INFORMATION CAPACITY OF DISCRETE MOTOR RESPONSES COMPARED FOR DIFFERENT DIRECTIONS AND AMPLITUDES OF MOVEMENT

by

Edison Earl Scholes

United States
Naval Postgraduate School

THESIS

INFORMATION CAPACITY OF DISCRETE MOTOR RESPONSES
COMPARED FOR
DIFFERENT DIRECTIONS AND AMPLITUDES OF MOVEMENT

by

Edison Earl Scholes

September 1970

Information Capacity of Discrete Motor Responses
Compared For
Different Directions and Amplitudes of Movement

by

Edison Earl Scholes
Major, United States Army
B.S., North Georgia College

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1970

ABSTRACT

This report describes the research and analysis conducted to determine if direction of movement has an effect on the movement and reaction times of personnel when completing discrete motor tasks in response to a visual stimulus. Information theory was an inherent part of the research and was used to specify more precisely an individual's capacity in this area. Twenty subjects participated in the experiment and a total of 2100 data points were recorded for each of the variables, movement time (MT) and reaction time (RT). The results of the research and analysis showed that direction of movement did have a significant effect on movement time but no significant effect on reaction time. Linear models were developed which characterize the effect that direction of movement has on movement time. The linear models developed were of the forms,

MT = a + b (Index of Difficulty) and

MT = a + b (Index of Difficulty) + c (Cosine X),

where X = angle of the direction of movement.

Multiple correlation analysis showed that a high, positive degree of correlation (R = .98) exists between movement time and the two variables - index of difficulty and direction of movement - used in the above models.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Man's ability to improve and predict the capabilities of the machine portion of man-machine systems has far outdistanced his ability to do the same for the man portion of these same systems. This situation continues even though experience and research have shown that considerable increases in the efficiency and safety of operation of both military and civilian systems can be attained by designing such systems with due regard for the motor, sensory, and intellectual capacities of the human operators.

This report addresses the area of discrete motor responses. These type responses are commonly involved in the operation of man-machine systems in both the military and civilian environments. Discrete motor responses can be defined simply as the movement of a limb (or limbs) as quickly as possible from one position in space to another. The research contained within this report is an extension of other research done in which information theory was used to specify more precisely man's capacities in this area of psychophysics.

II. BACKGROUND

Fitts and Peterson (1964) investigated the relationship between the information contained in a motor response, the movement time (MT) to accomplish the response, and the reaction time (RT) for the decision process associated with the response when a visual stimulus was used. They defined an index of difficulty (ID) as ID = $\text{Log}_2 \left[\frac{2A}{W}\right]$ (bits). A is defined as the movement amplitude or the distance from the initiation to the termination of a movement. W is defined as the range within which the movement must terminate. The index of difficulty (ID) is interpreted as the amount of information that a movement is required to generate. Using two targets of width W and a distance between starting button and targets of length A, Fitts' and Peterson's subjects (Ss) held a stylus at the starting button between the two targets and moved the stylus to the right or left target on presentation of the proper visual stimulus. RT and MT were measured, with subsequent analysis showing a linear relationship MT = a + b (ID) and a relative independence between RT and ID. A drawing of the equipment used by Fitts and Peterson (1964) is presented in Figure 1.

Poock, Breen and DeHaemer (1968) with equipment very closely resembling that used by Fitts and Peterson (1964) duplicated the experiment with the addition of auditory stimulation. Their results were highly consistent with those found by Fitts and Peterson (1964).

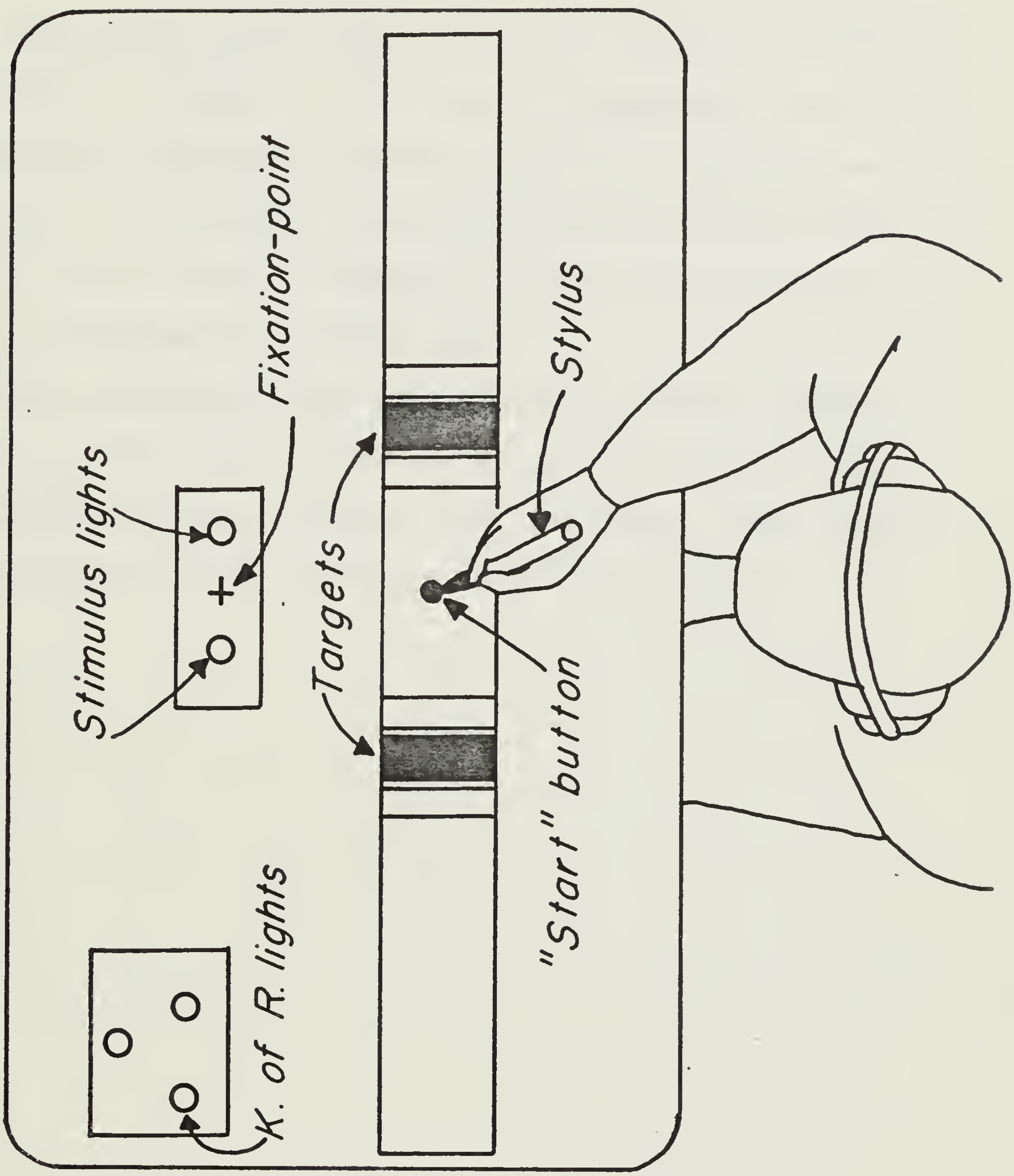

Figure 1. Plan view of the apparatus used by Fitts and Peterson (1964).

The results and relationships found during these two experiments are compared in Figure 2. Other studies and experiments have investigated discrete motor processes and some of these will be referred to in this report. The two experiments mentioned above, however, are the primary background for this research because of their application of information theory.

Fitts and Peterson (1964), Fitts (1954), and Poock, Breen and DeHaemer (1969) contain the information concerning the two experiments mentioned above. Attneave (1959) and Raisbeck (1964) contain background material on the subject of information theory.

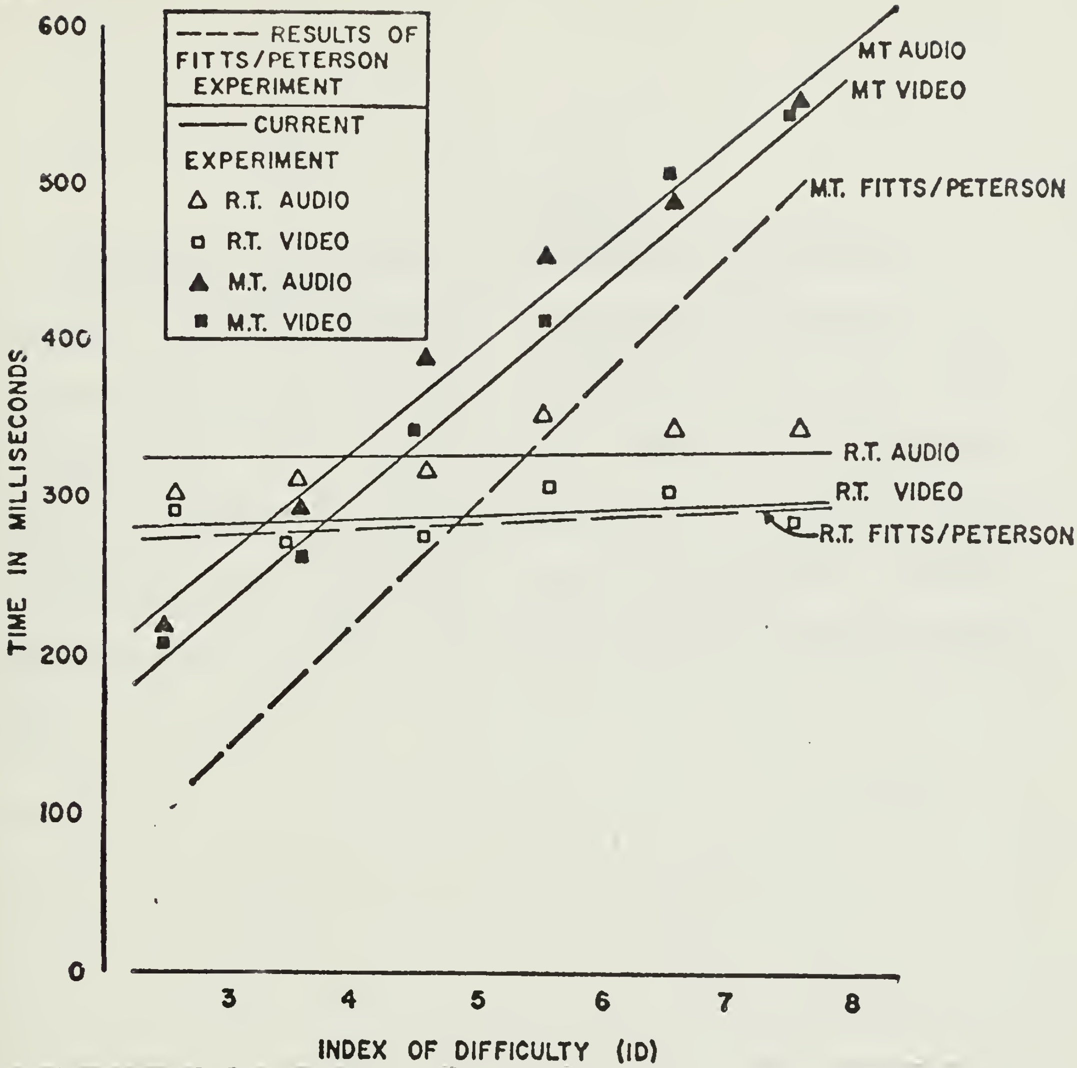

Figure 2. Comparison of results obtained by Fitts and Peterson (1964) and Poock, Breen and DeHaemer (1968). (Reprinted with the permission of G. K. Poock).

III. PURPOSE

The purpose of the present experiment was to determine if direction of movement would have an effect on the movement and reaction times of personnel when completing discrete motor tasks in response to a visual stimulus. The results of this experiment were to be compared with those found by Fitts and Peterson (1964) to determine if the relationship between the different variables were still consistent when additional directions of movement were used.

IV. METHOD

A. EXPERIMENTAL DESIGN AND APPARATUS

In order to add the variable of direction of movement, it was necessary to design the experiment and equipment differently than that used by Fitts and Peterson (1964). A glance at the equipment (Figure 1) used by Fitts and Peterson shows that the only directions of movement used in their experiment were to the right and left of the starting button. These left and right movements were made along the horizontal plane and parallel to the frontal plane of the subject's body. When the analysis of data was performed, Fitts and Peterson (1964) did not distinguish between these two directions of movement. In the present experiment, these same two directions were used, but were treated separately. Five additional directions of movement were added and these directions projected away from the starting point at different angles with respect to the horizontal plane. Three different ID levels were used in conjunction with the seven directions. In constructing the three ID levels, only amplitude was varied. Target width (W) was kept constant at 1 inch. The angular directions were placed on the experiment board in 30^{o} increments in order to get a maximum number of directions on the board without overly crowding the board. A drawing of the experiment board used is presented in Figure 3.

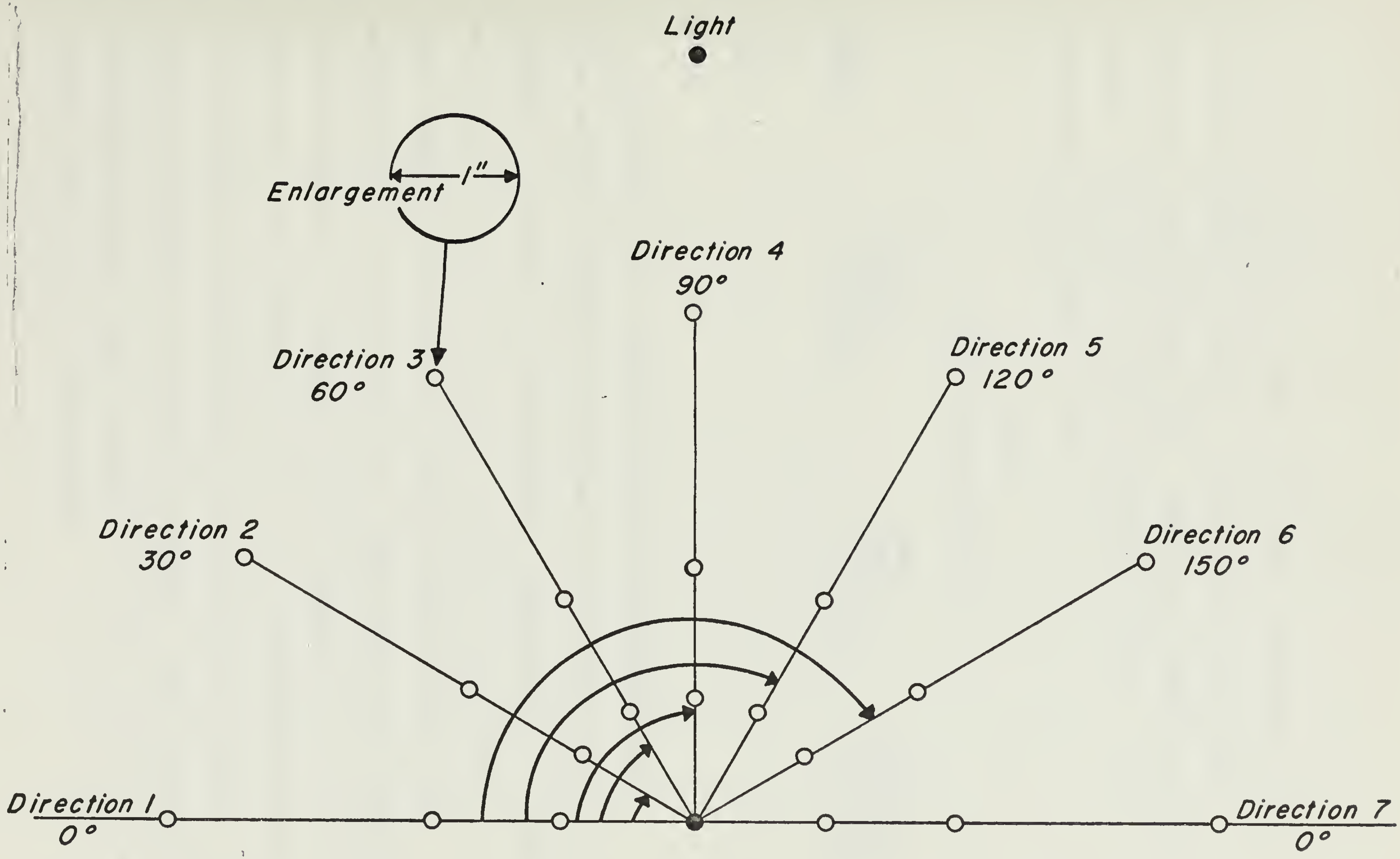

Figure 3. Drawing of experiment board showing directions and method of angular measurement used in experiment.

On each of the seven directions on the board, a target was placed at each of the three ID levels. A total of twenty-one targets were placed on the experiment board. These were numbered as shown on Figure 4 for ease of visual location by the subject. Target characteristics are shown in Table I.

TABLE I

Target Characteristics

Targets	Movement Amplitude (A, Inches)	Target Width (W, Inches)	Index of Difficulty (ID, Bits)
1-7	4	1	3
8-14	8	1	4
15-21	16	1	5

The design of this experiment differed significantly from those mentioned previously in the aspect of uncertainty as to the direction of movement. In this experiment, there was no uncertainty as to which direction of movement the response to the stimulus would require. The subjects were verbally given a target number and given time to visually locate that target prior to the initiation of each stimulation. This target number corresponded to a direction and ID level on the experiment board. The only uncertainty involved in the response was that uncertainty resulting from the subject's own amplitude variability in executing the movement. This experimental design was selected in order to localize, as much as possible, those variables which were not to be measured.

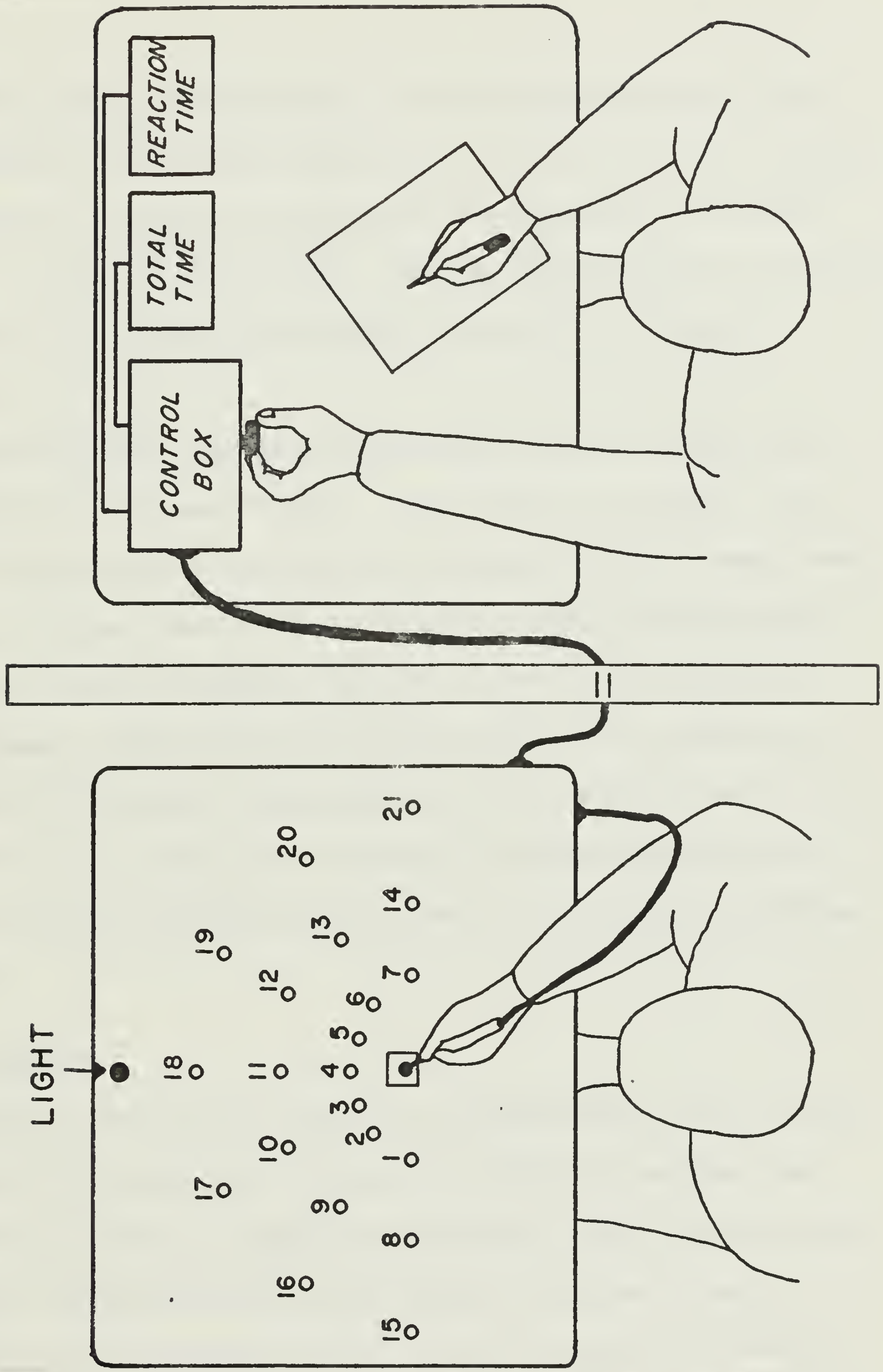

Figure 4. Plan view of the apparatus

The equipment was designed to measure the reaction time (RT) of a subject to the visual stimulus and the total time (TT) required of a subject to react to the stimulus and move from the starting button to the designated target. The experiment board was electrically connected to two timers and a master control box as shown in Figure 4.

The timer used to measure the reaction time was manufactured by Lafayette Instrument Company. Model number was 20225AD. The timer used to measure the total time required for the movement was a type S-1 timer, manufactured by Standard Electric Time Company. The only reason for using two different timers was availability of equipment. These two timers measured time to the nearest one-hundredth of a second. The remainder of the equipment used in the experiment was constructed locally with the advice and assistance of the Electrical Engineering Department at the Naval Postgraduate School.

B. PROCEDURE

Subjects were seated in front of the experiment board as shown in Figure 4. Considerable emphasis was placed on insuring that the subject's body was centered with respect to the starting button and that the frontal plane of the subject's body was parallel to the edge of the experiment board. From his location, the subject could not see the two timers or the master switch. To the subject's immediate front was a plain white wall which presented no distraction.

Subjects were read verbatim instructions as to the procedure to be followed. These instructions were:

> You are participating in an experiment which measures reaction time and movement time. You will be reacting to a visual stimulus which is the light on the board to your front. The reaction time measured will be the time required for you to react to this light. The movement time measured will be the time required for you to move from the starting button to a designated target. The targets are the round, numbered copper disks to your front. Please note the numbering sequence of the targets.
>
> You will grasp the stylus with your right hand and make contact with the starting button. At this time you will be given a target number. This target number will be given to you verbally by the experimenter after which you will locate that target visually. When the small light to your front comes on, you will move the stylus as quickly as you can to the designated target and make contact with that target. Shortly after you make contact with the target, the light will go off, at which time, you may return the stylus to the starting button. You are simulating the activity of a well-trained operator; therefore, if you miss a target or go to the wrong target, the same movement will be attempted again at a later time.
>
> During the experiment, please insure that you are sitting upright in the chair with the starting button centered with respect to your body. Do not rest your right arm on the board during the actual conduct of a trial and your left hand should remain in your lap so as not to obstruct your view. Allow me to reiterate that you are not to break contact with the starting button until you see the visual stimulus.
>
> What are your questions?

After the initial questions were answered, the subject was given five practice attempts. The times of these practice

attempts were recorded but the data was not used in the final analysis.

When the subject was in the starting position with the stylus on the starting button, the experimenter would verbally give the subject a target number. After the subject had located the target visually, the experimenter would turn on the master switch. This switch would turn on the visual stimulus and start the two timers. The equipment was constructed so that when the subject reacted to the visual stimulus and raised the stylus off the starting button, the reaction timer stopped. When the subject made contact with the designated target, the total timer stopped, at which time the experimenter recorded the reaction time (RT) and the total time (TT), reset the timers, and turned off the master switch. The subject would return the stylus to the starting button and the same procedure would follow. Each subject was given five trials through all the targets. During each of the five trials, every target was called one time. The target numbers were called in a different random sequence for each trial. These target numbers were called in the same sequence for each subject. Target numbers were called at a rate of four per minute. Subjects were given a one minute break between each trial. The results obtained during the conduct of the experiment were not discussed with the subjects.

C. SUBJECTS

The subjects used for the experiment were twenty, male graduate students who were randomly selected from the population at the Naval Postgraduate School. All subjects were military officers between the ages of 25 and 35. The mean age for the twenty subjects was 31.6. The only requirement placed on the selection of subjects was that they be right-handed. The subjects received no compensation for their efforts.

D. DISCUSSION

The equipment and experimental procedure were thoroughly tested in pilot runs prior to the initiation of the experiment. One important fact which was discovered during this phase was that the two timers differed by .03 of a second. The necessary correction to eliminate this difference was made by the experimenter during the conduct of the experiment and prior to recording the data.

In light of the number of subjects tested, which was considerably larger than the number tested in previous similar experiments, it was felt that the results of the experiment could be considered quite conclusive. In the areas where this report agrees with past research where a lesser number of subjects were tested, this research should provide considerable reinforcement of the relationships found to exist. In the areas of disagreement, the number of subjects tested should be a consideration when deciding the merits of the differences.

V. ANALYSIS OF DATA

A. REDUCTION OF DATA

Two times were recorded after each discrete movement made to a designated target. The first time recorded was reaction time (RT) and the second time recorded was total time (TT) required to react and complete the movement. Subsequent analysis verified previous experience that no learning occurred during the experiment, and each measure was, therefore, considered independent. A total of 2100 sets of times were recorded. These sets of times were combined in the equation MT = TT - RT to obtain 2100 readings for movement time (MT). There was no analysis conducted on total time (TT) as a separate variable. All times were recorded by target number, direction and ID level. Each of the 20 subjects made 5 discrete movements to each of the 21 targets. Since each of the 21 targets represented a particular ID level and direction, a total of 700 readings were recorded for both RT and MT for each ID level, and a total of 300 readings were recorded for both RT and MT for each direction used in the experiment. Mean movement times and mean reaction times were then computed and recorded for all categories of data. The analysis of the data obtained was greatly facilitated by the use of the IBM 360 computer located at the Naval Postgraduate School.

B. RESULTS

1. Analysis of Movement Time Data

a. Initial Comparison

The first analysis conducted on the MT data was a graph showing mean MT plotted for each direction and for each ID level. This graph is presented in Figure 5. This initial comparison showed that mean MT was different for each of the 7 directions and this difference seemed to be quite consistent for the 3 ID levels. The fastest mean MT for all ID levels is shown to exist in the area of directions 5 and 6. This graph also seems to indicate that some type of harmonic relationship might exist between the direction variable and MT.

b. Analysis of Variance Test

The MT data was analyzed by a two-way analysis of variance (ANOVA) to determine if direction of movement or ID had any effect on MT. The results of this ANOVA are presented in Table II.

TABLE II

ANOVA on MT Data

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Direction	6	0.817	0.136	17.365*
ID	2	13.700	6.850	873.746*
Direction X ID	12	0.138	0.012	1.467
Error	2079	16.307	0.008	
Total	2099	30.962		

*P < .01

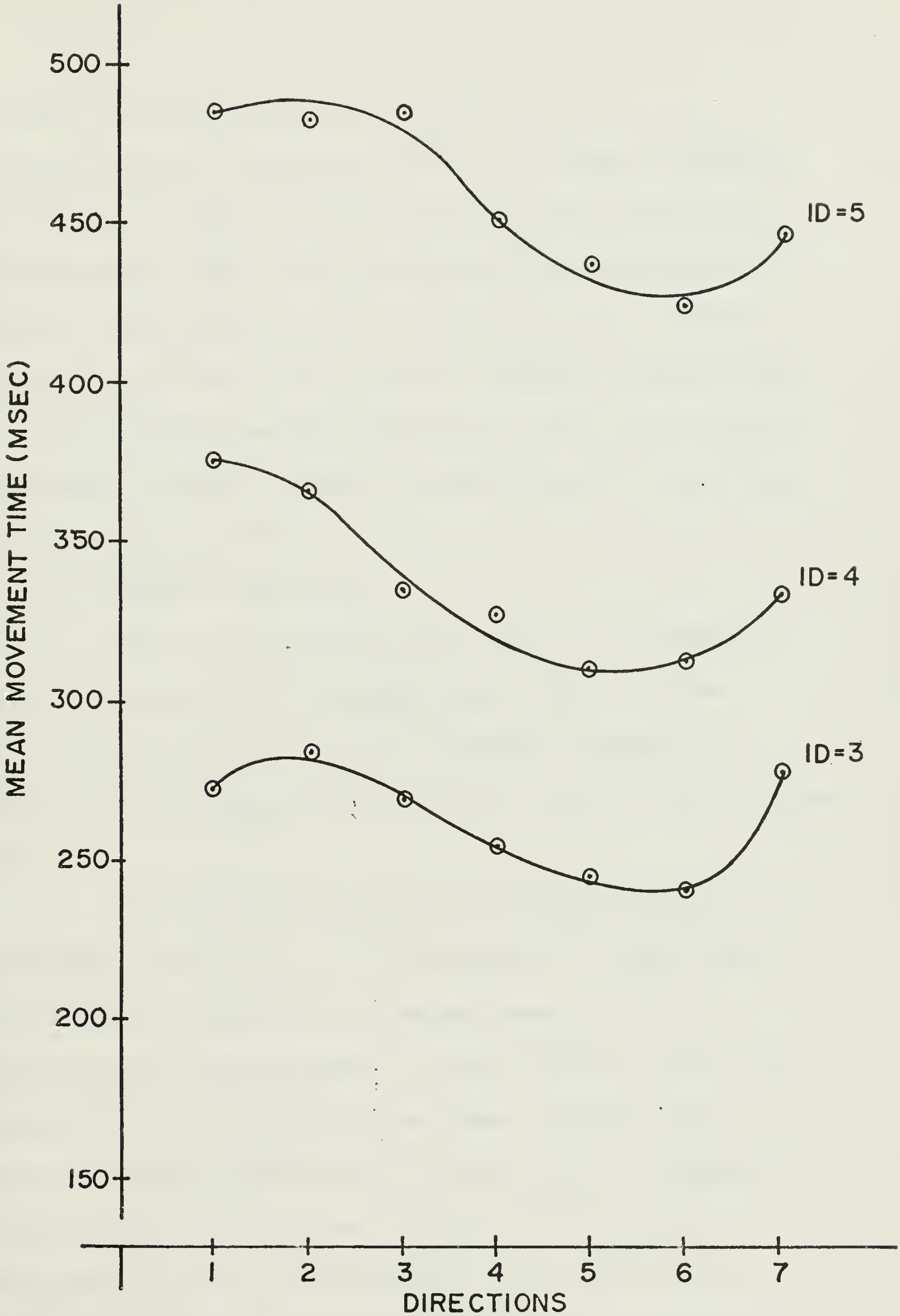

Figure 5. Initial comparison of MT data (Note: lines are only used to show general relationships).

From Table II it can be seen that both direction and ID were significant sources of variation for MT. The results regarding ID are highly consistent with those found by Fitts and Peterson (1964) and Poock (1968). The interaction between direction and ID was not a significant source of variation for MT. The above analysis also indicates that of the two variables, direction and ID, ID is the stronger source of variation for MT. The computer program used to compute this ANOVA was BMD02V which is described in detail in Dixon (1965).

c. Multiple Range Tests

Since direction and ID were shown to be significant sources of variation for MT, multiple range tests were then conducted on the MT data for each of these two variables to determine what differences existed between their individual treatment means.

The results obtained for the direction variable are summarized by Tables III and IV. From Table III it can be seen that direction 6 had the lowest (fastest) mean MT of the 7 directions used in the experiment. However, Table IV shows that although Direction 6 represented the lowest treatment mean, it cannot be considered significantly different than the treatment means represented by directions 4 and 5 at the .01 level of significance. It can be concluded from this analysis that for this experiment, direction 6 had the lowest mean MT and that, in

general, the lowest mean MT would be somewhere in the area between directions 4 and 6. This conclusion seems consistent with that reached by Schmidtke and Stier in their experiment which is discussed in McCormick (1964, page 219). Table IV also shows that the treatment means represented by directions 1 and 7 cannot be considered significantly different at the .01 level of significance. They were significantly different at the .05 level of significance. Fitts and Peterson (1964) did not distinguish between these two directions in their analysis of MT data. The results obtained by this analysis for the ID variable were more conclusive but were as expected.

TABLE III

Directions Ranked Lowest to Highest by Treatment Means

Direction	Rank
$1(0^{o})$	7
$2(30^{o})$	6
$3(60^{o})$	5
$4(90^{o})$	3
$5(120^{o})$	2
$6(150^{o})$	1
$7(0^{o})$	4

TABLE IV

Homogeneous Subsets

(Results obtained from Duncan Range Test. The treatment means of the directions connected by a line cannot be considered significantly different at the .01 level of significance).

RANK	1	2	3	4	5	6	7
DIRECTION	6	5	4	7	3	2	1
HOMOGENEOUS SUBSETS	—	—	—				
		—	—	—			
			—	—	—		
				—	—	—	—

TABLE V

ID Levels Ranked Lowest to Highest by Treatment Means

ID		Rank
3	-	1
4	-	2
5	-	3

From Table V it can be seen that the treatment means of the 3 ID levels are ranked as would be expected since ID level, as presented in this experiment, was increased by increasing amplitude of movement. A second table showing homogeneous subsets is not presented for ID levels since all 3 ID levels proved to be

significantly different at the .01 level of significance. There were no homogeneous subsets. It can be concluded that MT increases with ID level and that increase is significantly different at each ID level. This result provides strong reinforcement to the relationships found by Fitts and Peterson (1964).

The multiple range test analysis was accomplished by use of the computer program BMD07V. The detailed explanation and references for this program are contained in Dixon (1965). The data which was used in this analysis consisted of all the 2100 data points collected on MT.

d. Regression and Correlation Analysis

A regression analysis was performed on the MT data with MT as the dependent variable and ID as the independent variable. This analysis was performed for each of the 7 directions used in the experiment and each result was compared with the results found by Fitts and Peterson (1964). It should be noted here that Fitts' and Peterson's experiment included an ID range of 2.58 through 7.58 and a movement amplitude range of 3 to 12 inches. The linear regression equation, MT = 74 ID - 70 msec, found by Fitts and Peterson, was used for the comparison of the results found during this experiment. The results of the regression analysis on MT data are shown in Table VI and Figures 6a-6g.

TABLE VI

Linear Regression Equations Obtained for MT

Direction	Equation
$1(0^{o})$	MT = 107 ID - 49 msec
$2(30^{o})$	MT = 100 ID - 22 msec
$3(60^{o})$	MT = 109 ID - 72 msec
$4(90^{o})$	MT = 98 ID - 48 msec
$5(120^{o})$	MT = 97 ID - 57 msec
$6(150^{o})$	MT = 92 ID - 42 msec
$7(0^{o})$	MT = 85 ID - 12 msec

A homogeneity of regression test, which is described by Steel (1960), was accomplished on the regression coefficients of the equations found during this experiment and the coefficient found by Fitts and Peterson. This test compared each of the slopes of the 7 regression lines against the slope of the line found by Fitts and Peterson to determine whether or not they could be considered to be estimates of a common slope (β). A level of significance of .01 was used for the test. The null hypothesis (H_o) was that the slope (β_i) of the regression line found for direction i (i = 1,..., 7) minus the slope (β_F) of the regression line found by Fitts and Peterson (1964) was equal to zero. The critical values of two different alternative hypotheses (H_1) were found by use of the Student-t distribution table. The results obtained by the comparison

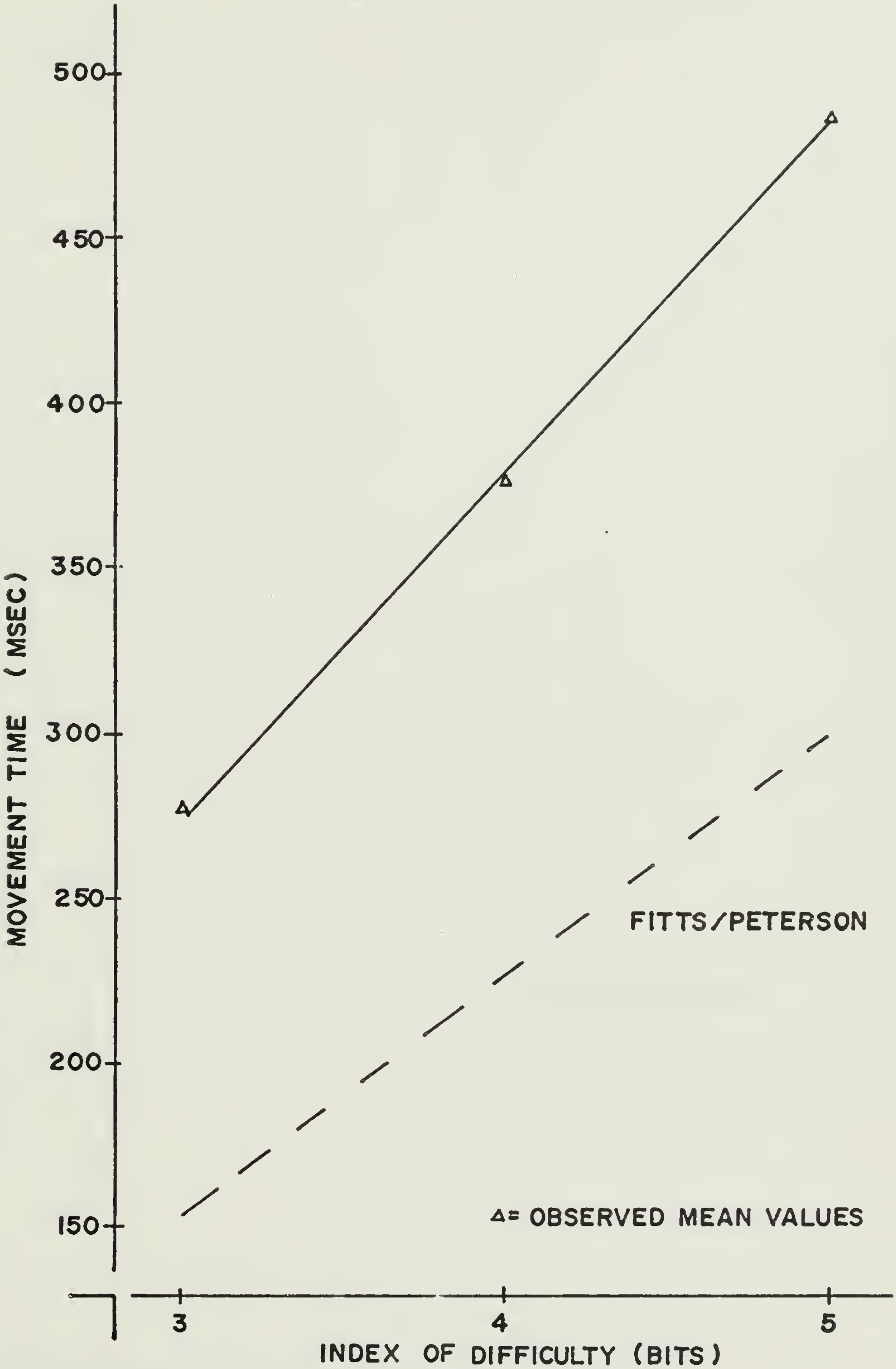

Figure 6a. Regression line for MT data - direction 1.

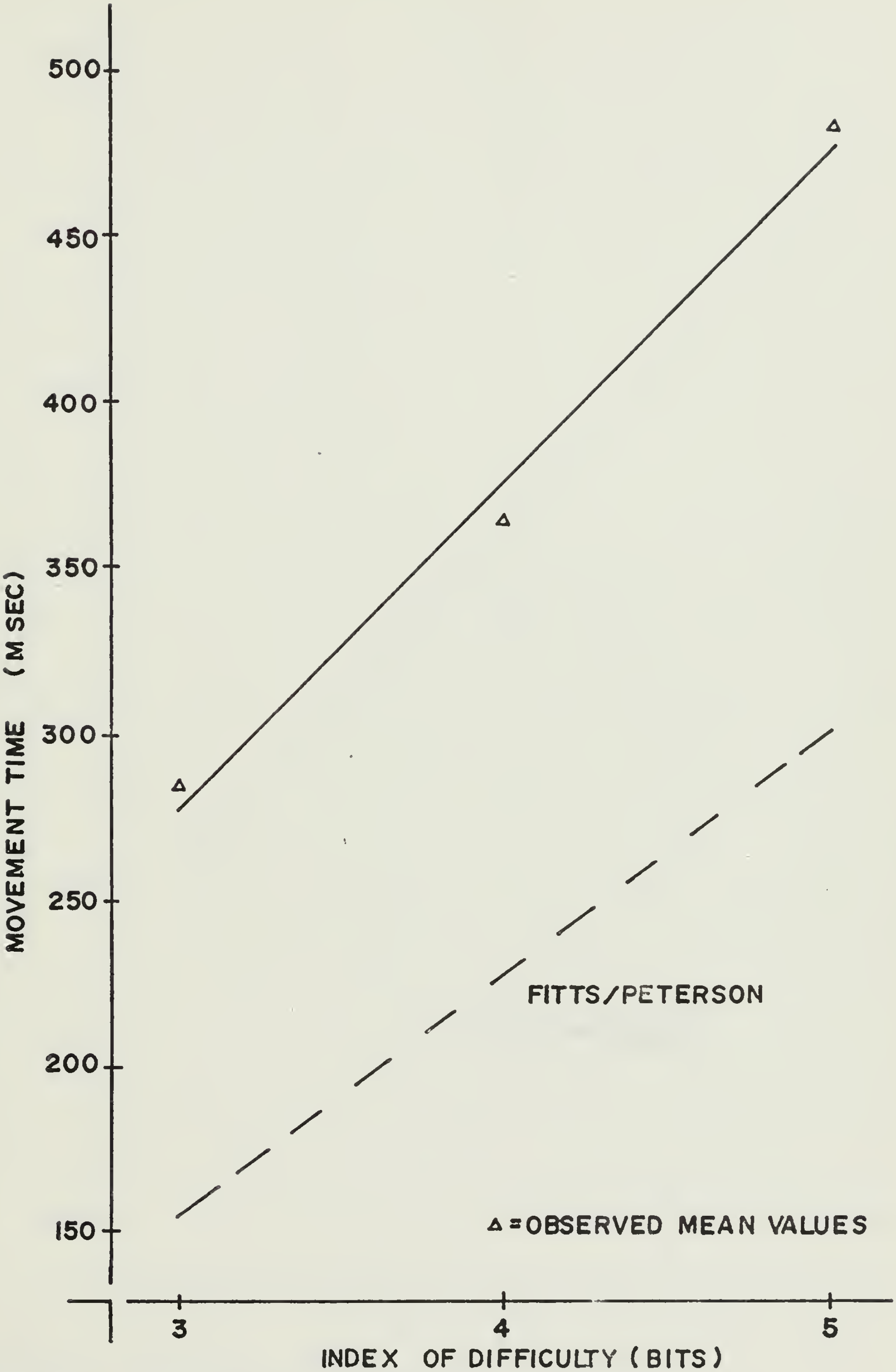

Figure 6b. Regression line for MT data - direction 2.

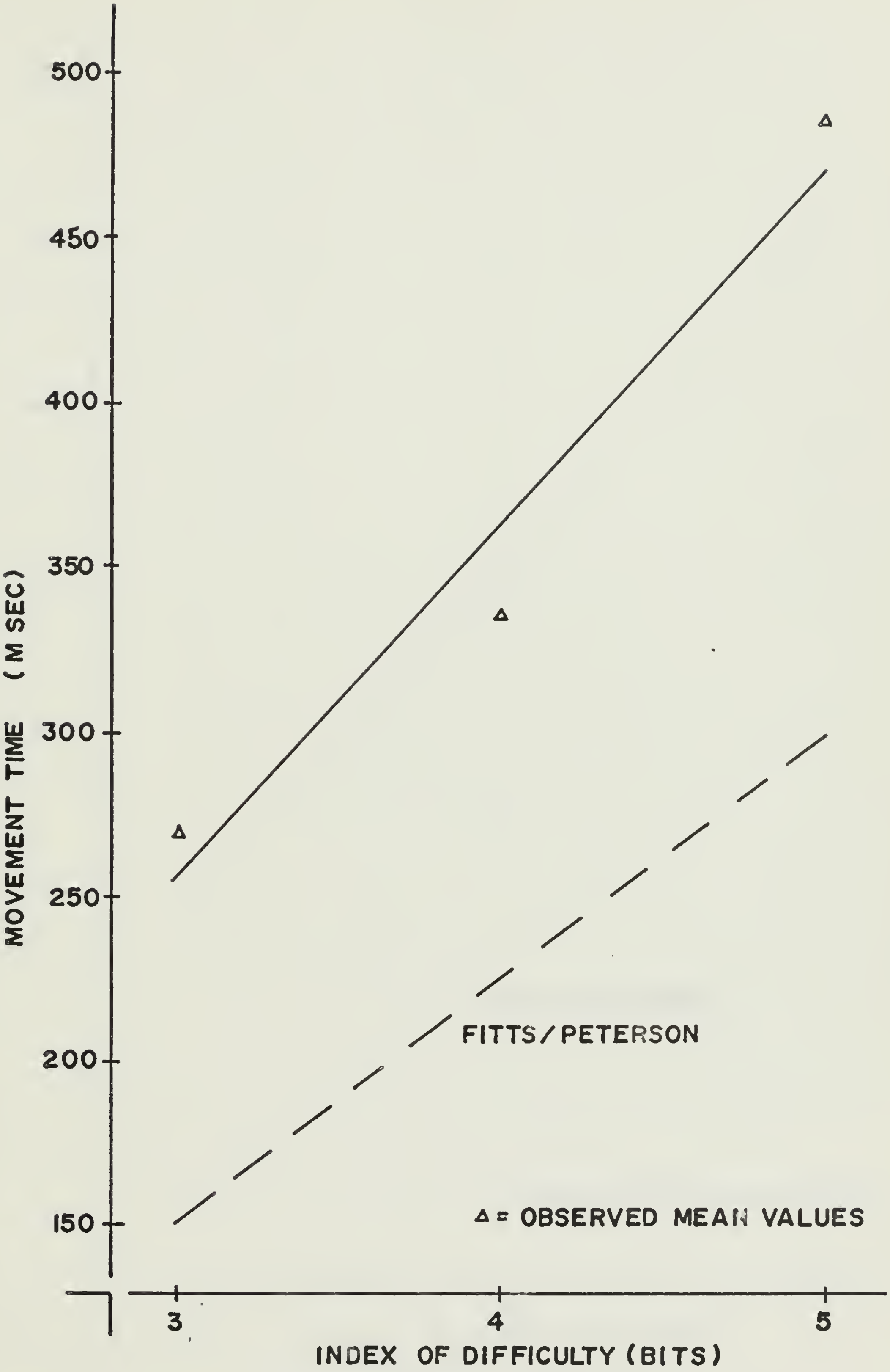

Figure 6c. Regression line for MT data - direction 3.

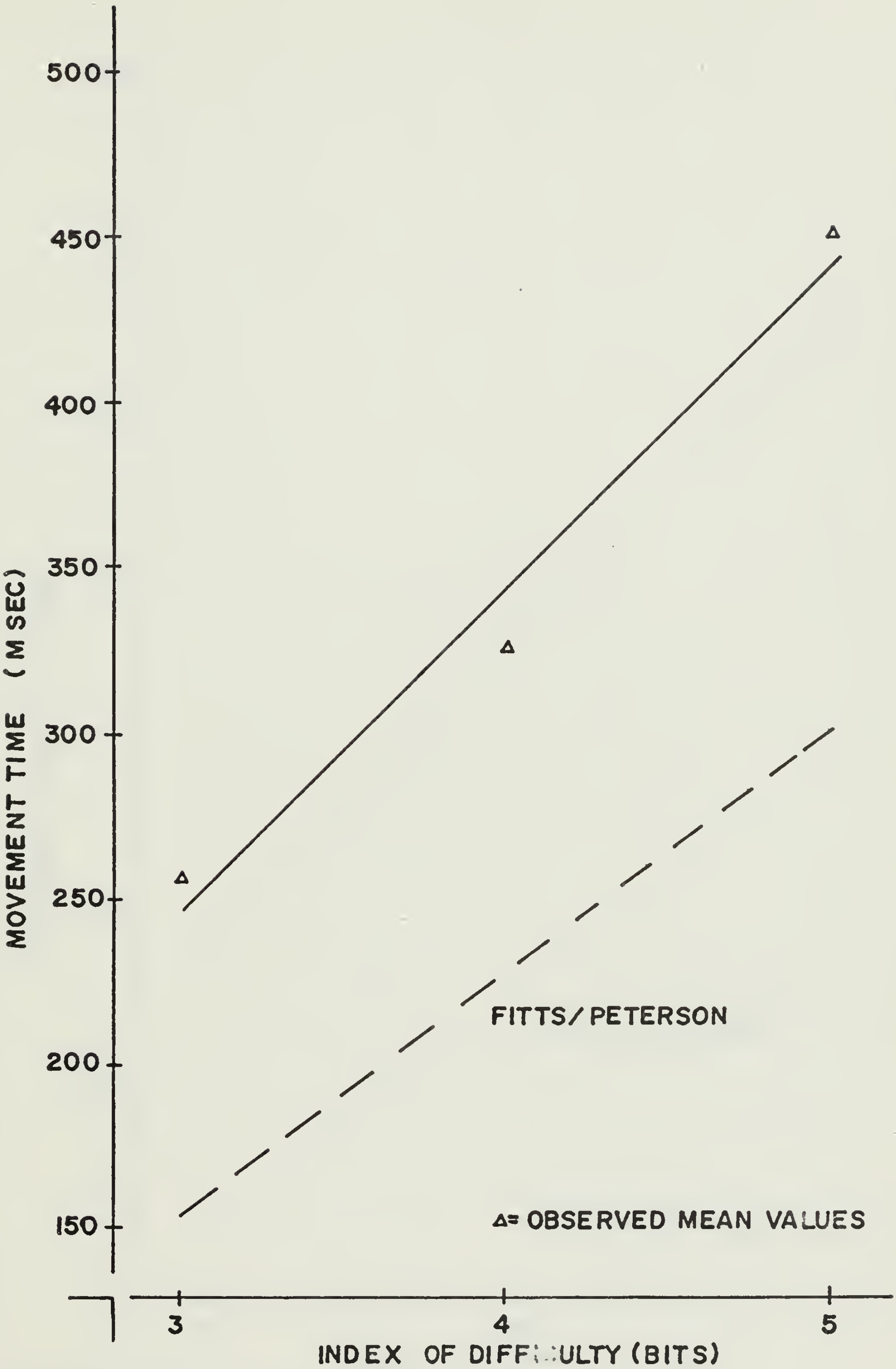

Figure 6d. Regression line for MT Data - direction 4.

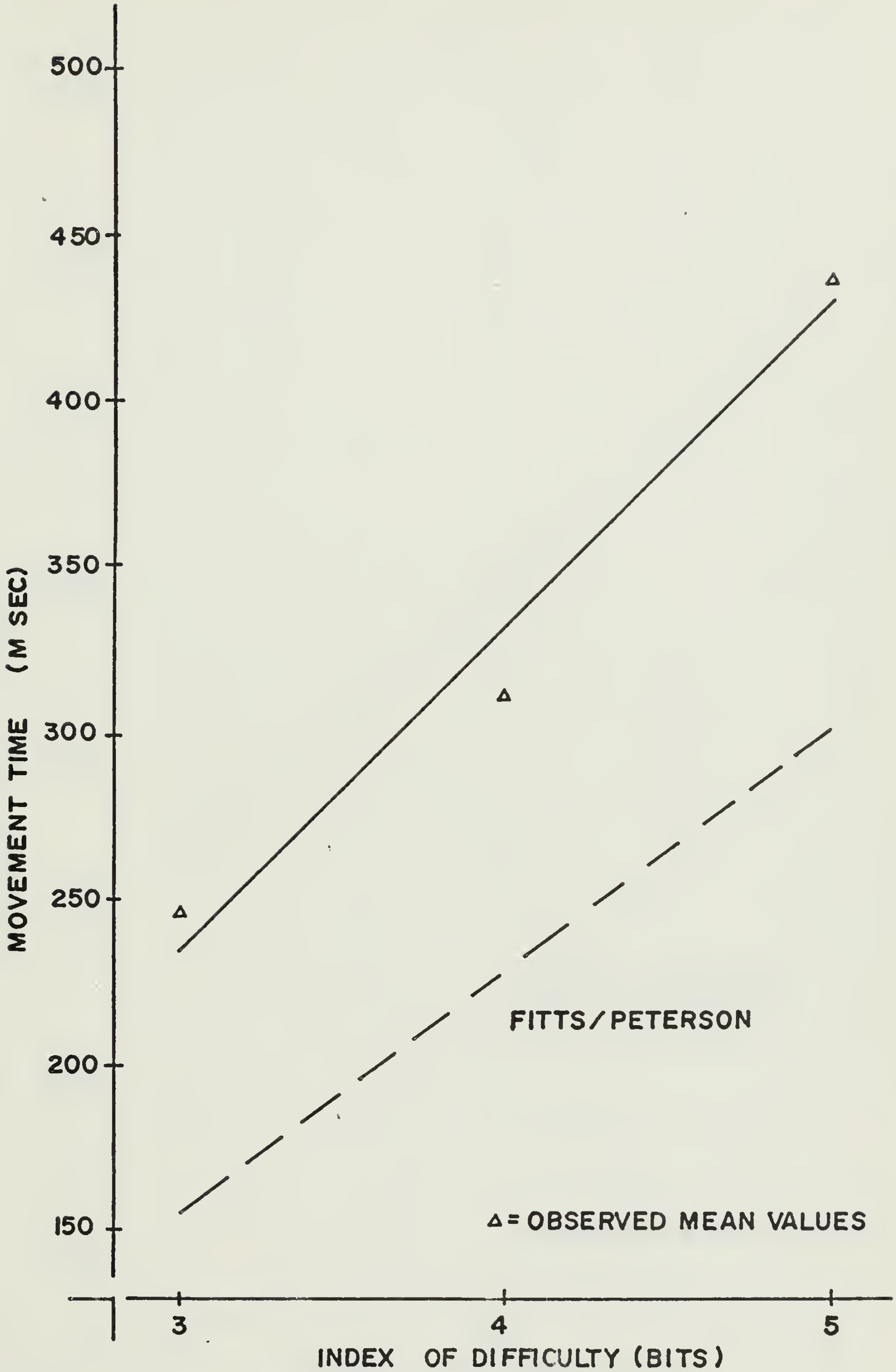

Figure 6e. Regression line for MT data - direction 5.

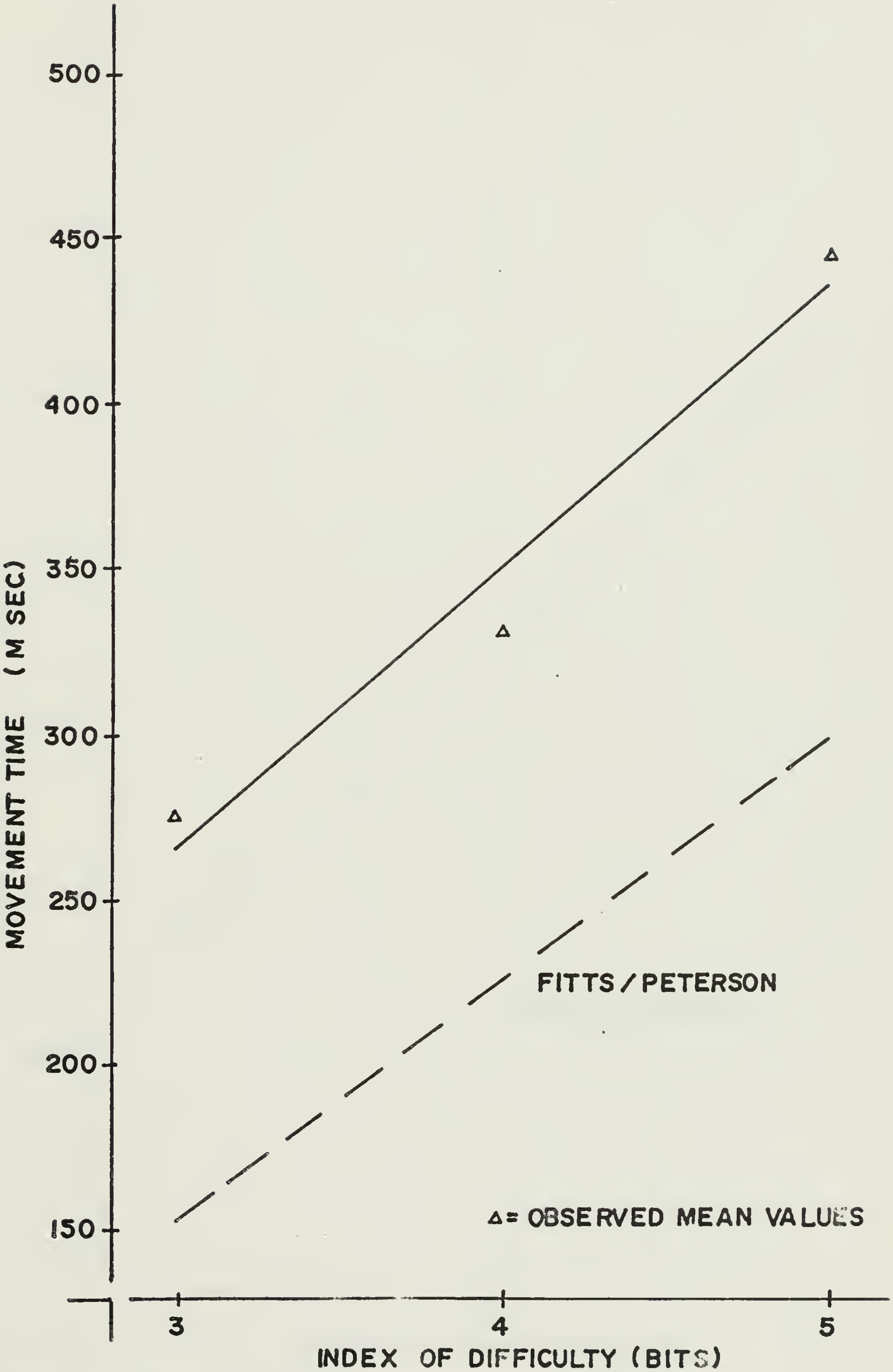

Figure 6g. Regression line for MT data - direction 7.

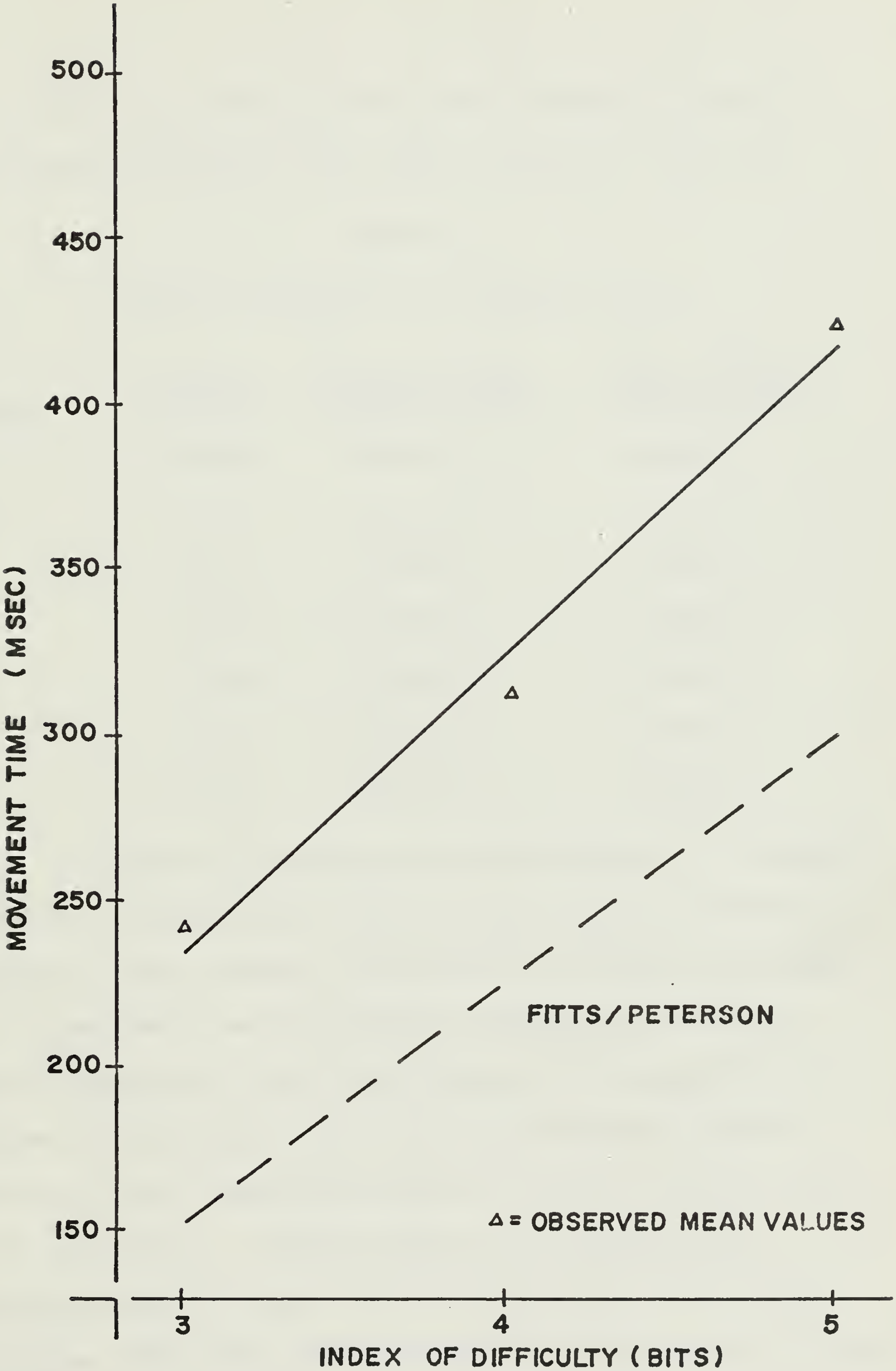

Figure 6f. Regression line for MT data - direction 6.

of the critical values with the calculated values were the same for both alternative hypotheses. The results are shown in Table VII.

TABLE VII

Results of Homogeneity of Regression Tests

Direction	Calculated t value	$H_1: \beta_i - \beta_F \neq 0$ $(t_{.005,2} = 9.925)$	$H_1: \beta_i - \beta_F > 0$ $(t_{.01,2} = 6.965$
1	12.290	Reject H_o	Reject H_o
2	9.936	Reject H_o	Reject H_o
3	6.261	Accept H_o	Accept H_o
4	6.396	Accept H_o	Accept H_o
5	5.332	Accept H_o	Accept H_o
6	5.578	Accept H_o	Accept H_o
7	3.116	Accept H_o	Accept H_o

It should be noted here that the homogeneity of regression analysis was accomplished with the use of mean data since that was all that was locally available from Fitts' and Peterson's experiment. It can be concluded from the regression analysis that our results compare favorably with those found by Fitts and Peterson with some exceptions. From Figures 6a-6g it can be seen that the regression lines show the same relationship between ID and MT as the line found by Fitts and Peterson. The MT's found by this experiment were consistently higher for similar ID levels than those found by Fitts and Peterson. This could possibly be explained by equipment differences, differences in ages of subjects, or differences in the amount of motor

movement necessary to accomplish the tasks. As can be seen from Table VII, the slope of the regression lines found for each direction were significantly the same as the slope of the line found by Fitts and Peterson with the exception of the slope of the lines found for directions 1 and 2. This would seem to indicate that even though direction is a significant source of variation for MT as shown by Table II, the basic relationship between MT and ID as found by Fitts and Peterson (1964) is further verified with the exception of movements made in the area of directions 1 and 2.

A correlation analysis was then performed to determine the measure of association or correlation (r) between MT and ID. This was accomplished first by the use of all data points and then by the use of mean data. The correlation coefficient (r) was found between MT and ID for each of the 7 directions. The results of this analysis are shown in Table VIII.

TABLE VIII

Correlation Coefficients for MT as a Function of ID

Direction	r (All Data)	r (Mean Data)
1	.71	.99
2	.70	1.0
3	.68	.94
4	.67	.99
5	.65	.98
6	.64	.96
7	.61	.97

It can be concluded from this analysis that MT has a high, positive degree of association with ID. The results found with the use of mean data are highly consistent with that ($r = .99$) found by Fitts and Peterson (1964). The results found with the use of all data points provide considerable strength to the theory of the relationship between MT and ID, particularly, when it is remembered that a total of 2100 data points on MT were used to obtain relatively high, positive correlation coefficients. No explanation can be offered for the uniformly decreasing r found with the use of all data points.

2. Analysis of Reaction Time Data

a. Initial Comparison

The first analysis performed on the RT data was a graph showing mean RT plotted for each direction and for each ID level. This graph is presented in Figure 7. This initial comparison of RT data showed that RT remained relatively constant for each ID level and direction. The graph indicated that RT is slightly more stable at an ID level of 4, but it could not be determined from this analysis if this represented a significant difference. Direction of movement did not seem to have a noticeable effect on RT.

b. Analysis of Variance Test

The RT data was analyzed by a two-way analysis of variance (ANOVA) to determine if direction of movement or ID actually had an effect on RT. The results of this ANOVA are presented in Table IX.

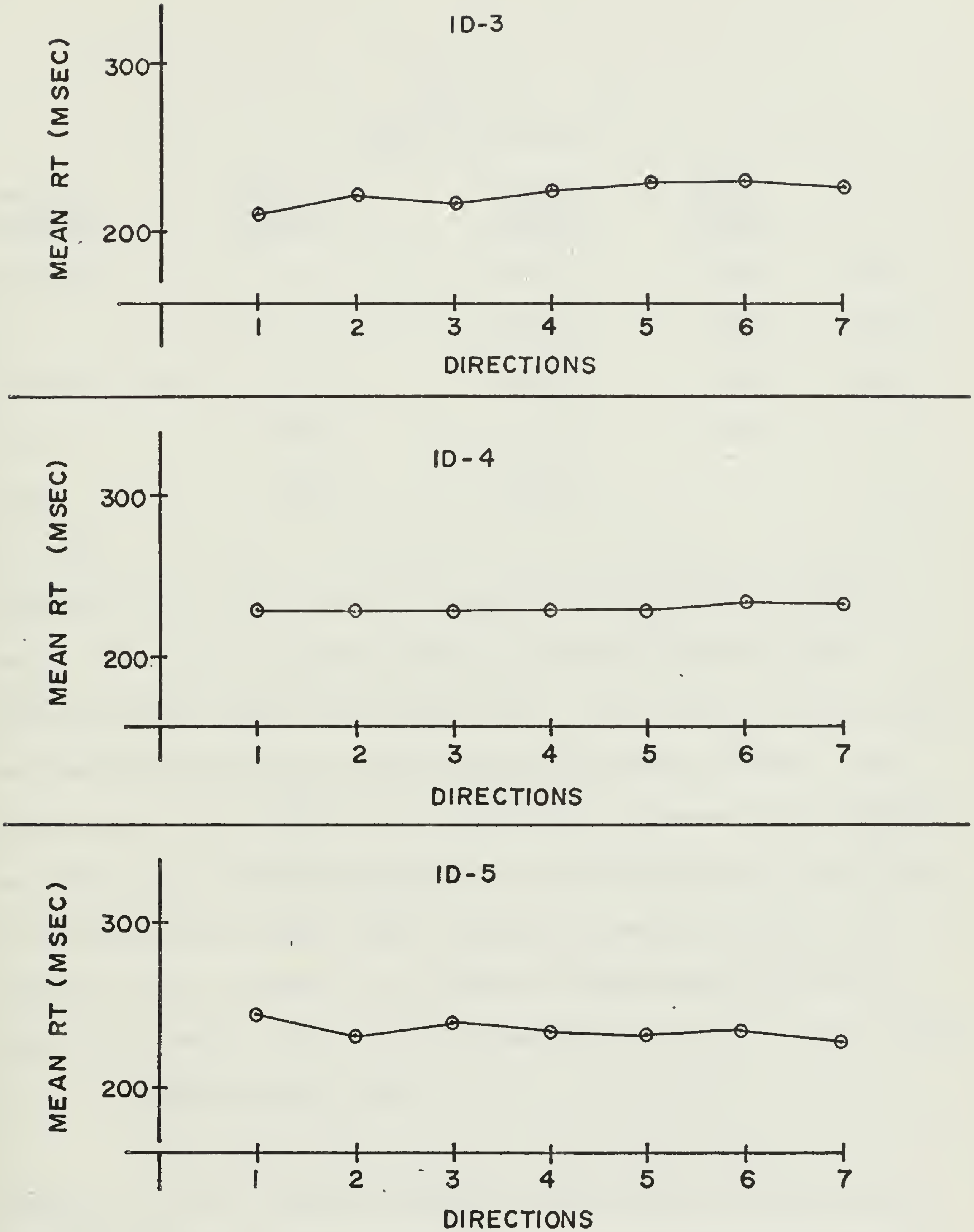

Figure 7. Initial comparison of RT data (Note: Lines are only used to show general relationships).

TABLE IX

ANOVA on RT Data

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F
Direction	6	0.013	0.002	0.824
ID	2	0.040	0.020	7.780*
Direction X ID	12	0.038	0.003	1.240
Error	2079	5.304	0.003	
Total	2099	5.394		

*P < .01

From Table IX it can be seen that only ID had a significant effect on RT. Direction of movement and the interaction between ID and direction had no significant effect on RT. The results of this analysis are consistent with those found by Fitts and Peterson (1964). Fitts and Peterson did not experiment with directional movement specifically, but found that RT was approximately the same for movements made in the two directions they used. They, therefore, combined the data for identical pairs of targets. The computer program BMDO2V was used to compute this ANOVA. This program is described in detail in Dixon (1965).

c. Multiple Range Test

Since ID was shown to be a significant source of variation for RT, a multiple range test was conducted on the RT data for this variable to determine what difference existed between the 3 treatment means. The results obtained from this analysis are shown in Tables X and XI.

TABLE X

ID Levels Ranked Lowest to Highest by Treatment Means

ID		Rank
3	-	1
4	-	2
5	-	3

TABLE XI

Homogeneous Subsets

(Results obtained from a Duncan Range Test. The treatment means of the ID levels connected by a line cannot be considered significantly different at the .01 level of significance).

Rank	1	2	3
ID	3	4	5
Homogeneous Subsets			

It could only be concluded from this analysis that ID level 3 represented the lowest treatment mean, but at the .01 level of significance it could not be considered significantly different than that represented by ID level 4.

d. Regression and Correlation Analysis

A regression analysis was performed on the RT data with RT as the dependent variable and ID as the independent variable.

This analysis was performed for each of the 7 directions used in the experiment and each result was compared with the results found by Fitts and Peterson (1964). The linear regression equation, RT = 5.4 ID + 261 msec, found by Fitts and Peterson was used for the comparison. The results of the regression analysis on RT data are shown in Table XII and Figures 8a-8g.

TABLE XII

Linear Regression Equations Obtained for RT

Direction	Equation
$1(0^{o})$	RT = 15.0 ID + 168 msec
$2(30^{o})$	RT = 4.4 ID + 210 msec
$3(60^{o})$	RT = 10.5 ID + 186 msec
$4(90^{o})$	RT = 4.7 ID + 212 msec
$5(120^{o})$	RT = 1.0 ID + 228 msec
$6(150^{o})$	RT = 2.6 ID + 225 msec
$7(0^{o})$	RT = -0.7 ID + 233 msec

The reaction times found during this experiment were consistently lower than those found by Fitts and Peterson (1964) because of the absence of uncertainty in this experiment. Even though direction of movement has been shown to have no significant effect on RT, the regression analysis indicates that ID has a slightly greater effect on RT for directions 1 through 4. For directions 5 through 7, RT is relatively constant over the 3 ID levels.

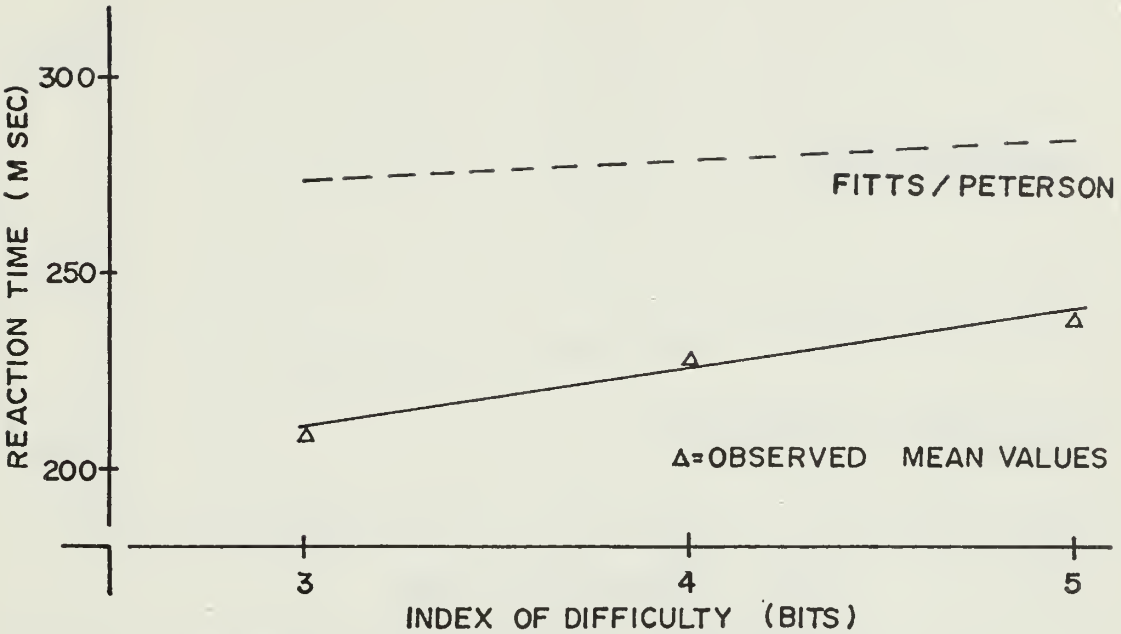

Figure 8a. Regression line for RT data - direction 1.

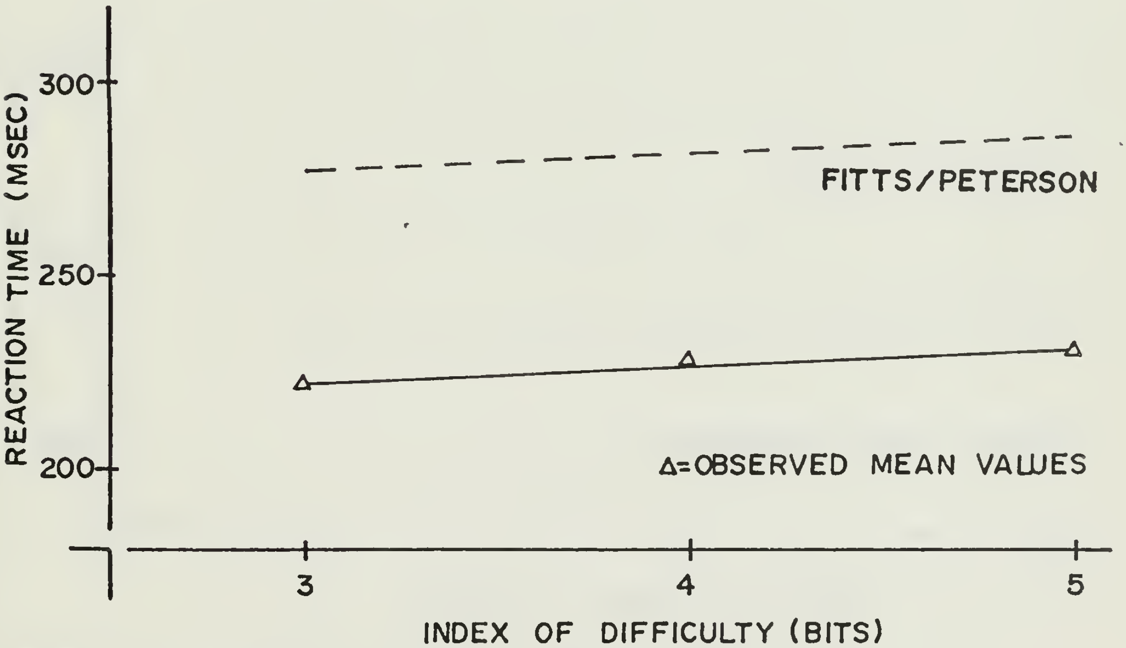

Figure 8b. Regression line for RT data - direction 2.

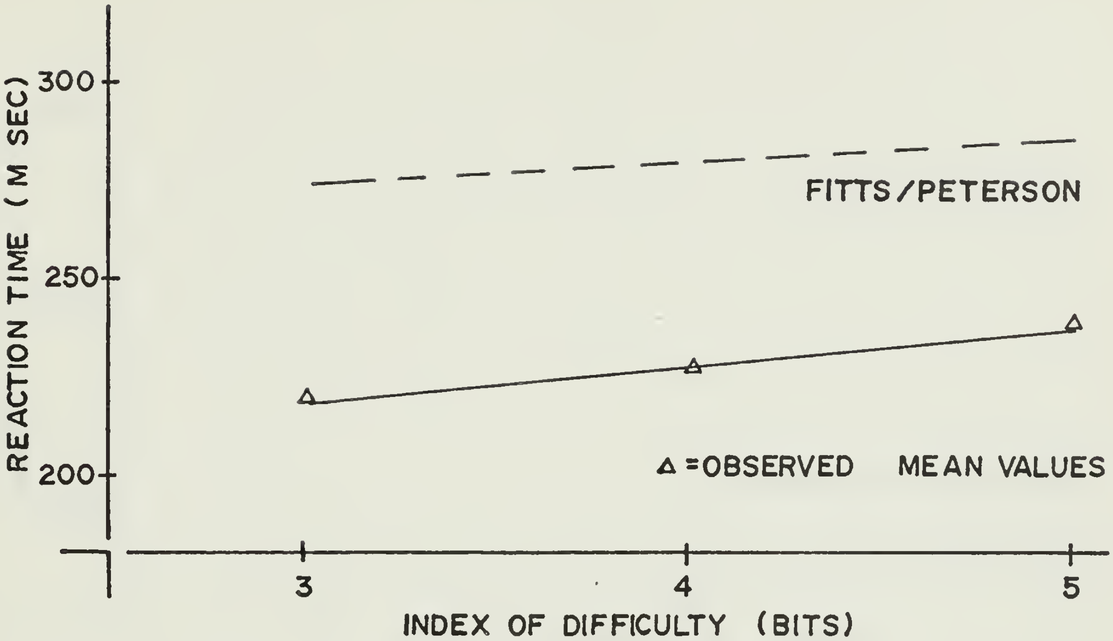

Figure 8c. Regression line for RT data - direction 3.

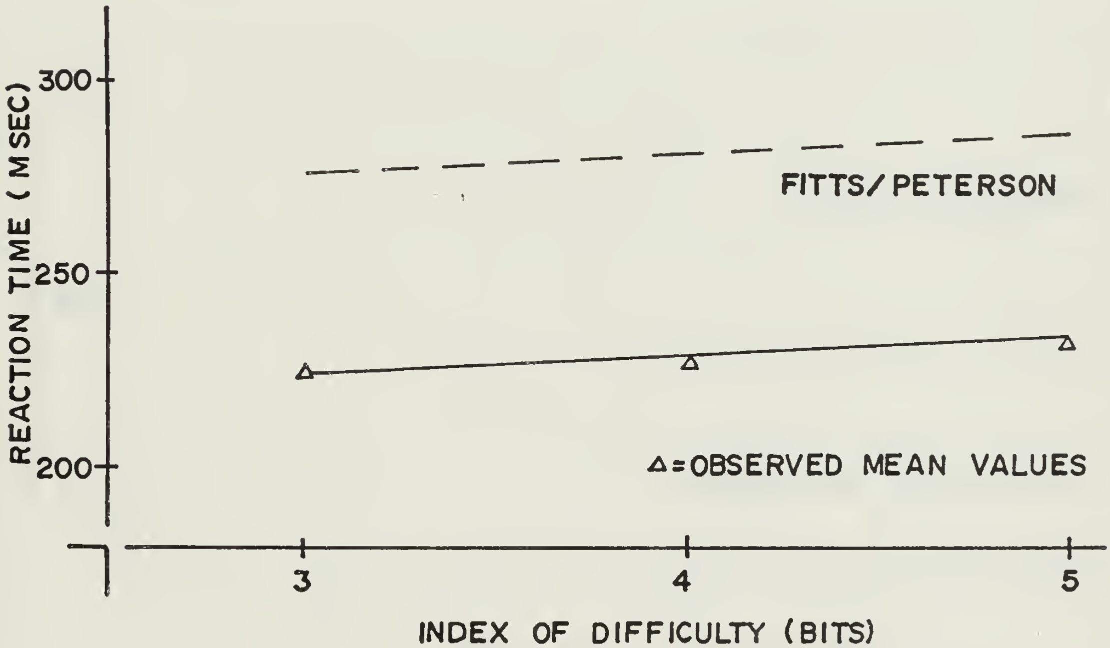

Figure 8d. Regression line for RT data - direction 4.

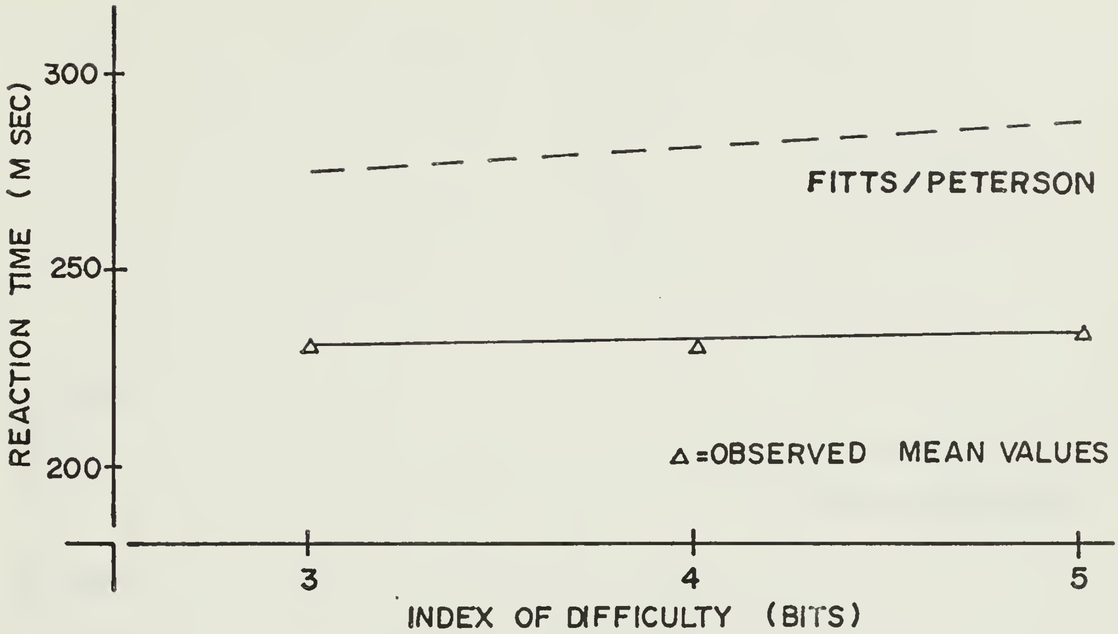

Figure 8e. Regression line for RT data - direction 5.

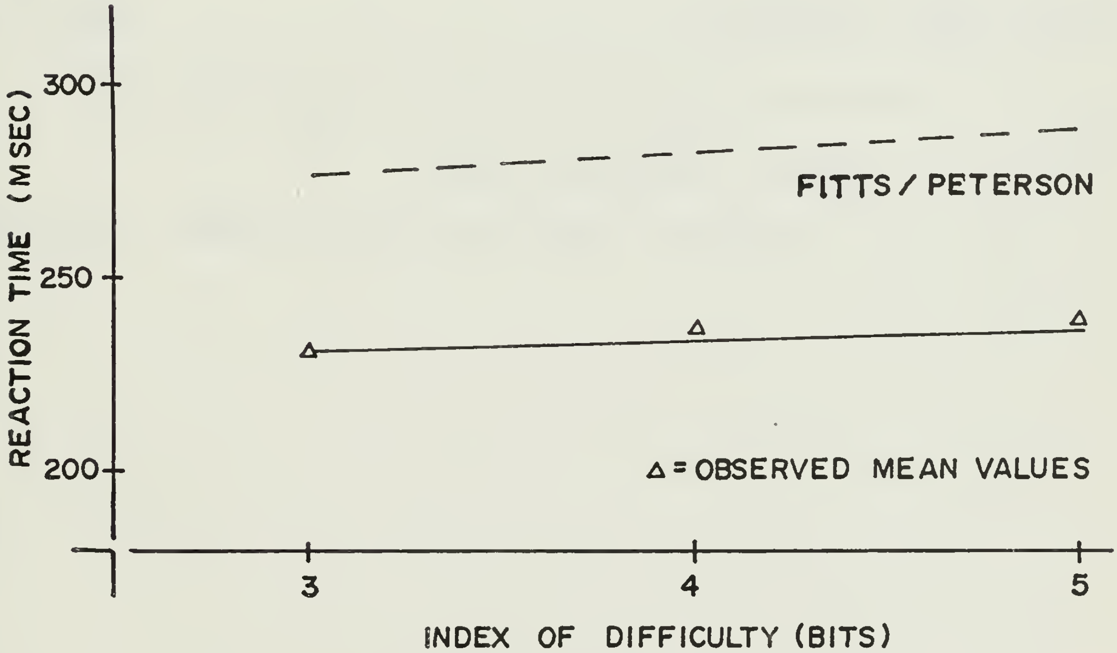

Figure 8f. Regression line for RT data - direction 6.

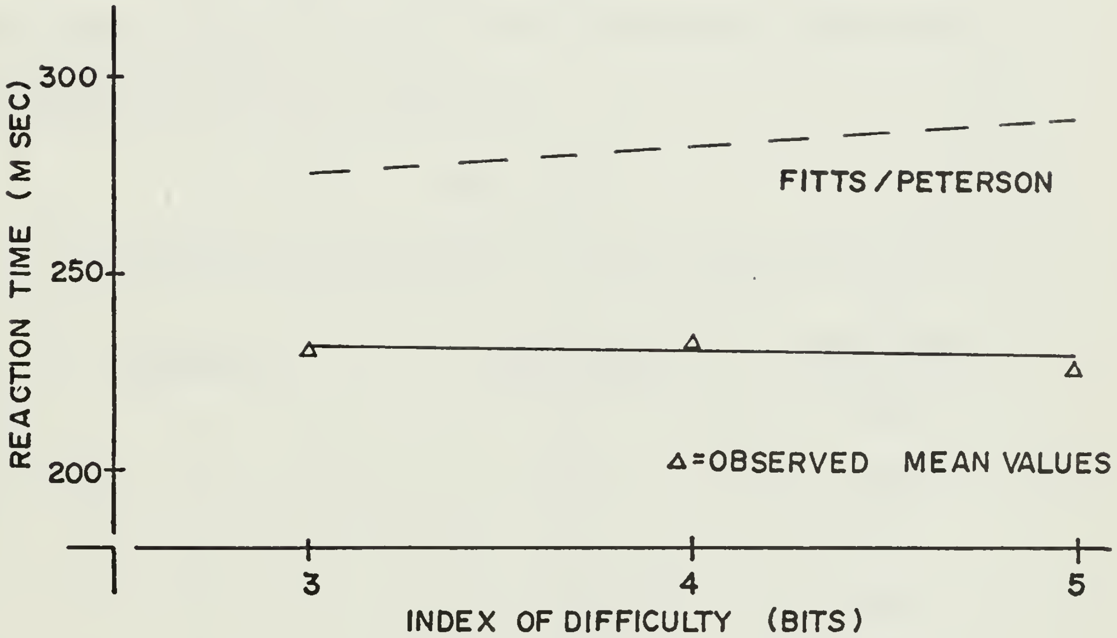

Figure 8g. Regression line for RT data - direction 7.

A correlation analysis was then performed to determine the measure of association or correlation (r) between RT and ID. This analysis was accomplished first by the use of all data points and then by the use of mean data. The correlation coefficient (r) was found between RT and ID for each of the 7 directions. The results of this analysis are shown in Table XIII.

TABLE XIII

Correlation Coefficients for RT as a Function of ID

Direction	r (All Data)	r (Mean Data)
1	.23	.99
2	.07	.98
3	.17	.99
4	.08	.99
5	.02	.65
6	.04	.99
7	-.01	-.32

It can be concluded from this analysis that mean RT has a high, positive degree of association with ID for all directions except direction 7. No explanation can be offered for the exception of direction 7. These are consistent with the results found by Fitts and Peterson (1964) when they used mean data. The correlation coefficient found by Fitts and Peterson was .79, but they used more than 3 ID levels in their experiment and analysis. This relationship between ID and RT is not maintained when all data points are used

to determine the correlation coefficient. As can be seen from Table XIII, when all data points are used in the analysis, ID and RT are relatively independent. There is also evidence here to support the argument that whatever effect ID has on RT, that effect is slightly greater when movement is made in directions 1, 2, 3, or 4.

3. <u>Correlation Analysis Between Movement Time and Reaction Time Data</u>

A correlation analysis was performed to determine the degree of association between the two variables, MT and RT. This was computed with the use of the 2100 data points recorded for each of the variables. The correlation coefficient found was 0.10. This result is additional evidence as to the independence of the two variables. This result is consistent with that found by Fitts and Peterson (1964).

4. <u>Multiple Regression Analysis on Movement Time Data</u>

After it had been shown that both direction and ID had a significant effect on MT, an effort was then made to quantify the direction variable. This effort was begun with the idea that if the direction variable could be quantified, then a general equation could be developed for predicting MT in any direction. At this point in the analysis, there existed only the simple regression equations for predicting MT for each of the 7 specific directions used in the experiment. The same computer program which computed the ANOVA shown in Table II also computed the orthogonal polynomial components for the variables, ID and direction. These components indicated that the relationship between each of these two variables and MT

was primarily a linear one. With this in mind, a stepwise multiple linear regression analysis was then performed with MT as the dependent variable and with direction and ID as the independent variables. The direction variable was quantified by use of the angular measurements of the 7 directions of movement. Several transgenerations were tried with the direction variable, but the cosine and sine functions were found to be the best measures of the existing relationship. The level of significance used for inclusion of the two variables, ID and direction, into the stepwise regression equation was .01. The results of the analysis showed that both variables were significant enough to be included in the equation. The equation found by use of the cosine function of the angle of movement was:

$MT = -45 + 98\ ID + 25\ (\text{Cosine } X)$ msec, where X = angle of direction of movement.

The multiple correlation coefficient (R) was computed to determine the degree of association between the two variables - ID and Cosine X - and MT. The R found by use of mean MT data was .98. The R found by use of all data points was .75. This general equation was then used to determine a regression line showing the relationship between ID and MT for each of the 7 directions used in the experiment. These regression lines were compared with the simple regression lines found previously. As can be seen from Figures 9a-9g, the multiple regression line computed with use of the general formula provides a good fit to the regression lines computed previously for each specific direction.

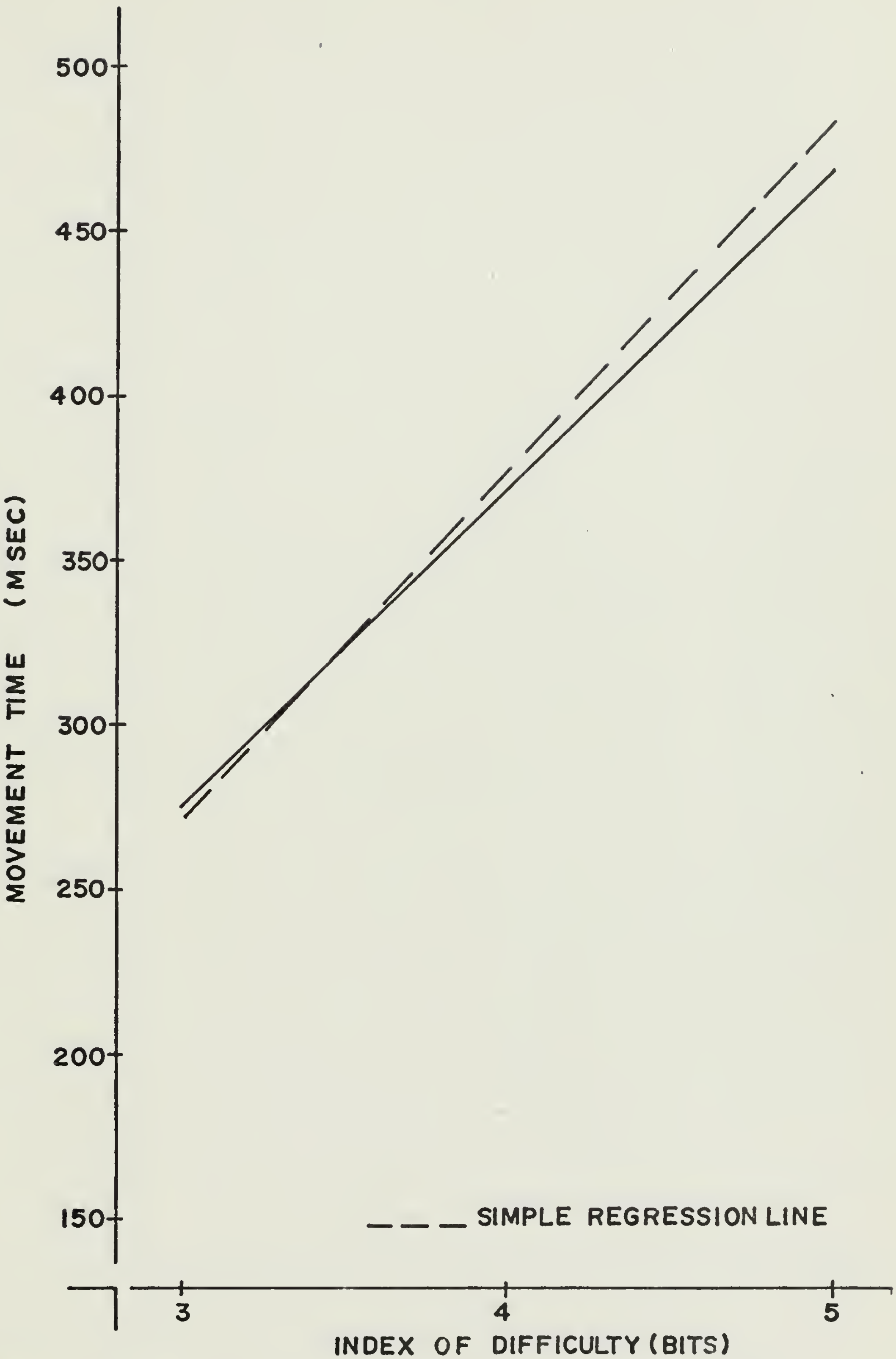

Figure 9a. Comparison of multiple regression line with simple regression line - direction 1.

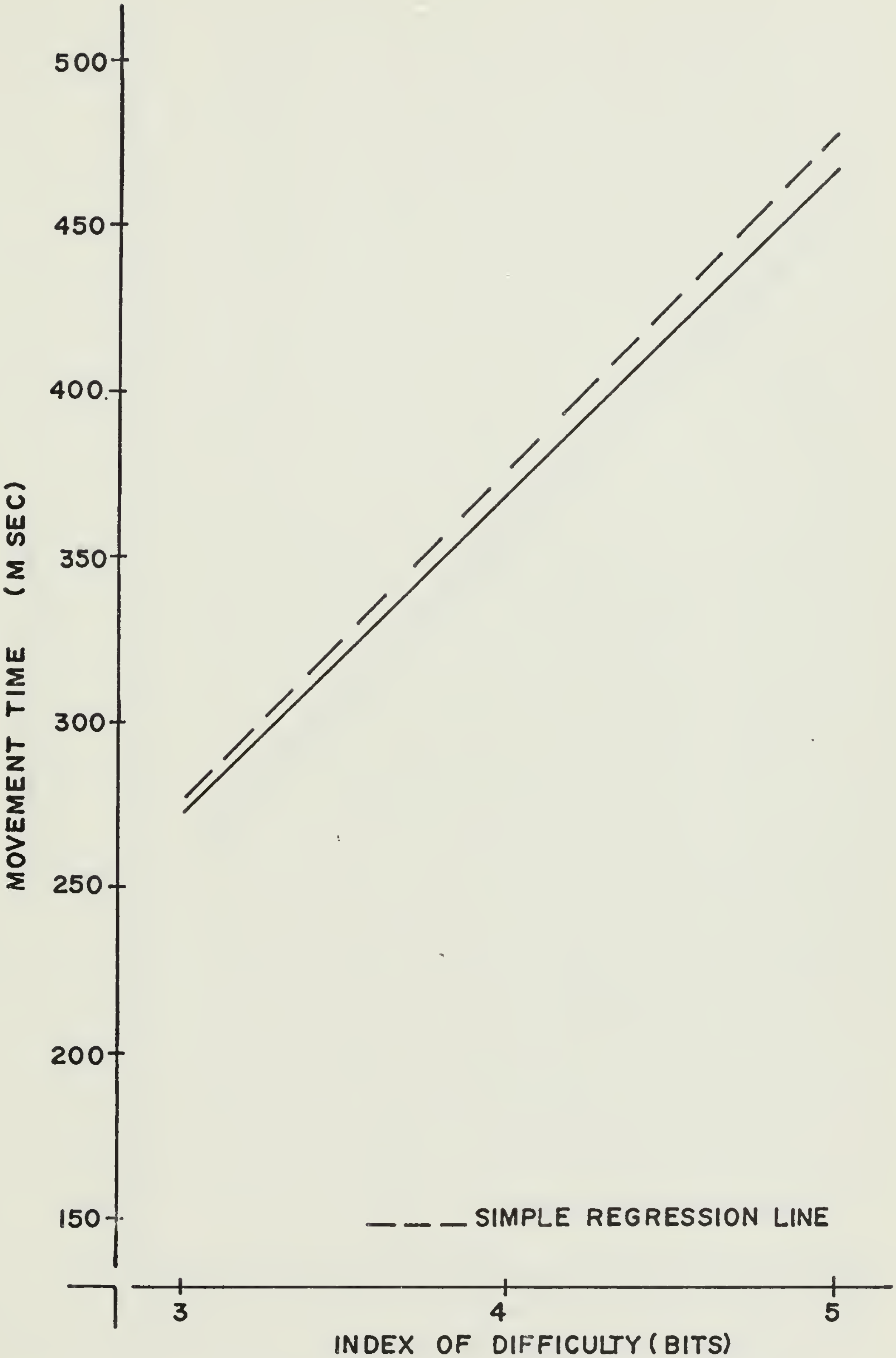

Figure 9b. Comparison of multiple regression line with simple regression line - direction 2.

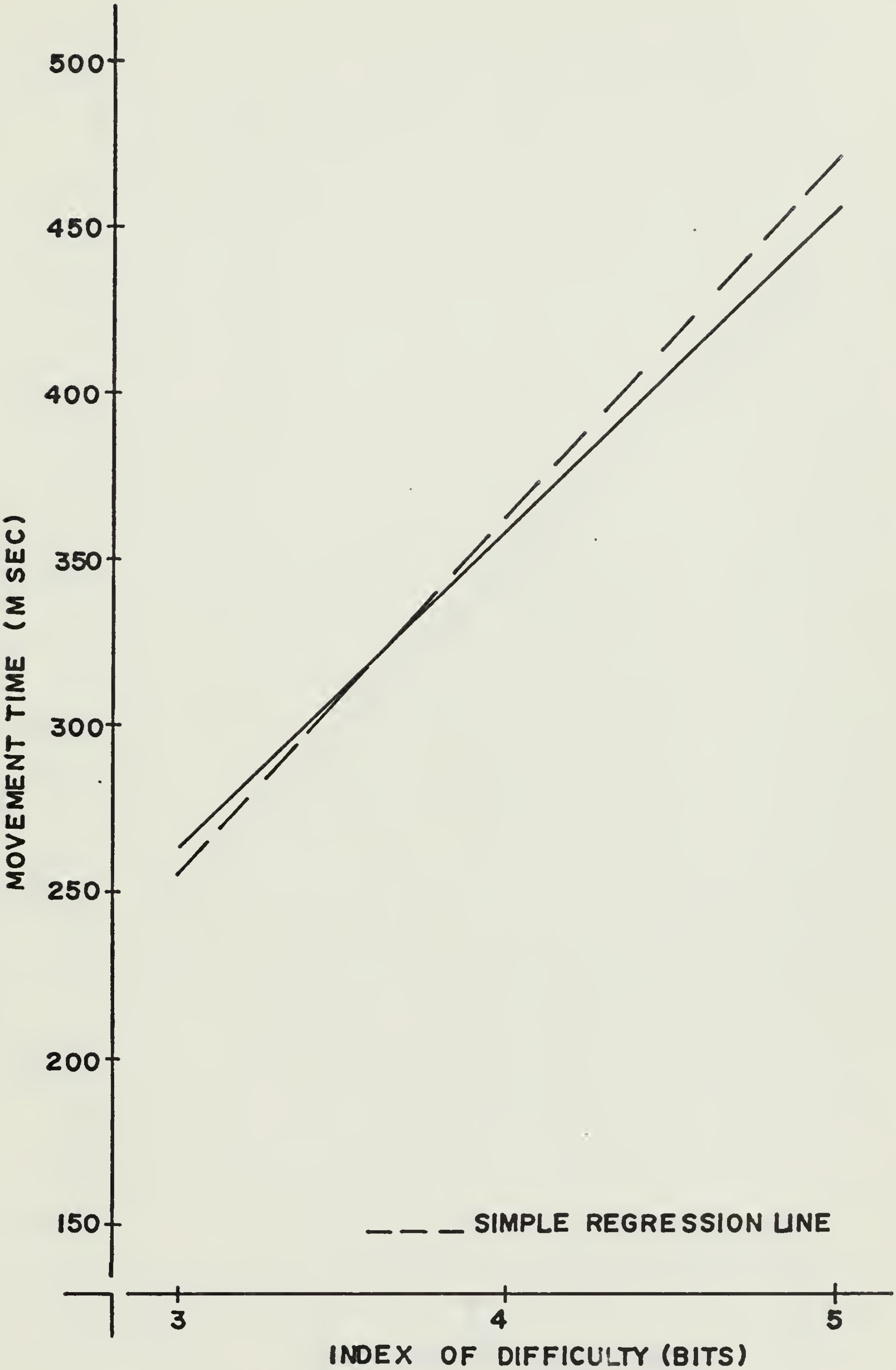

Figure 9c. Comparison of multiple regression line with simple regression line - direction 3.

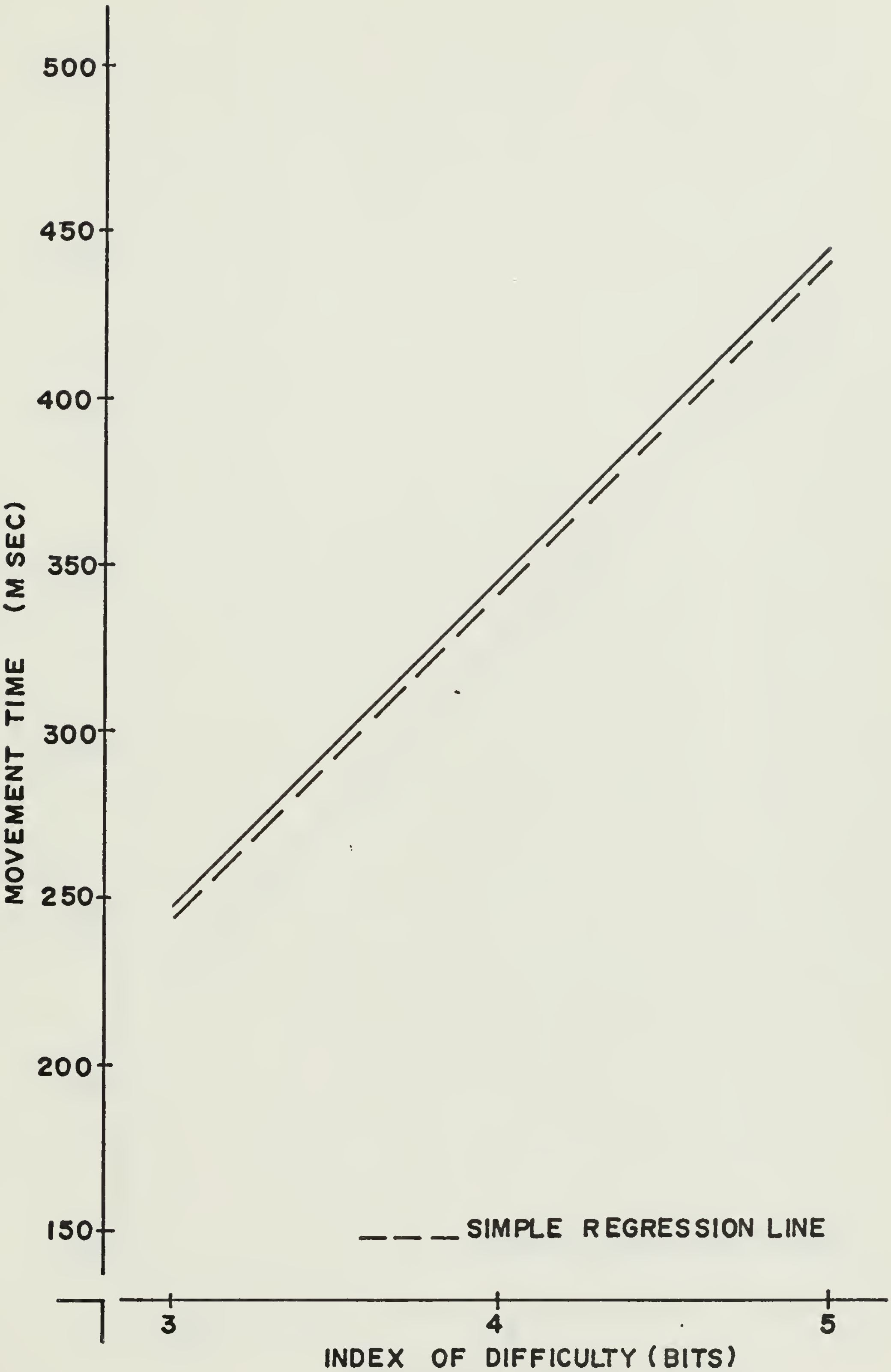

Figure 9d. Comparison of multiple regression line with simple regression line - direction 4.

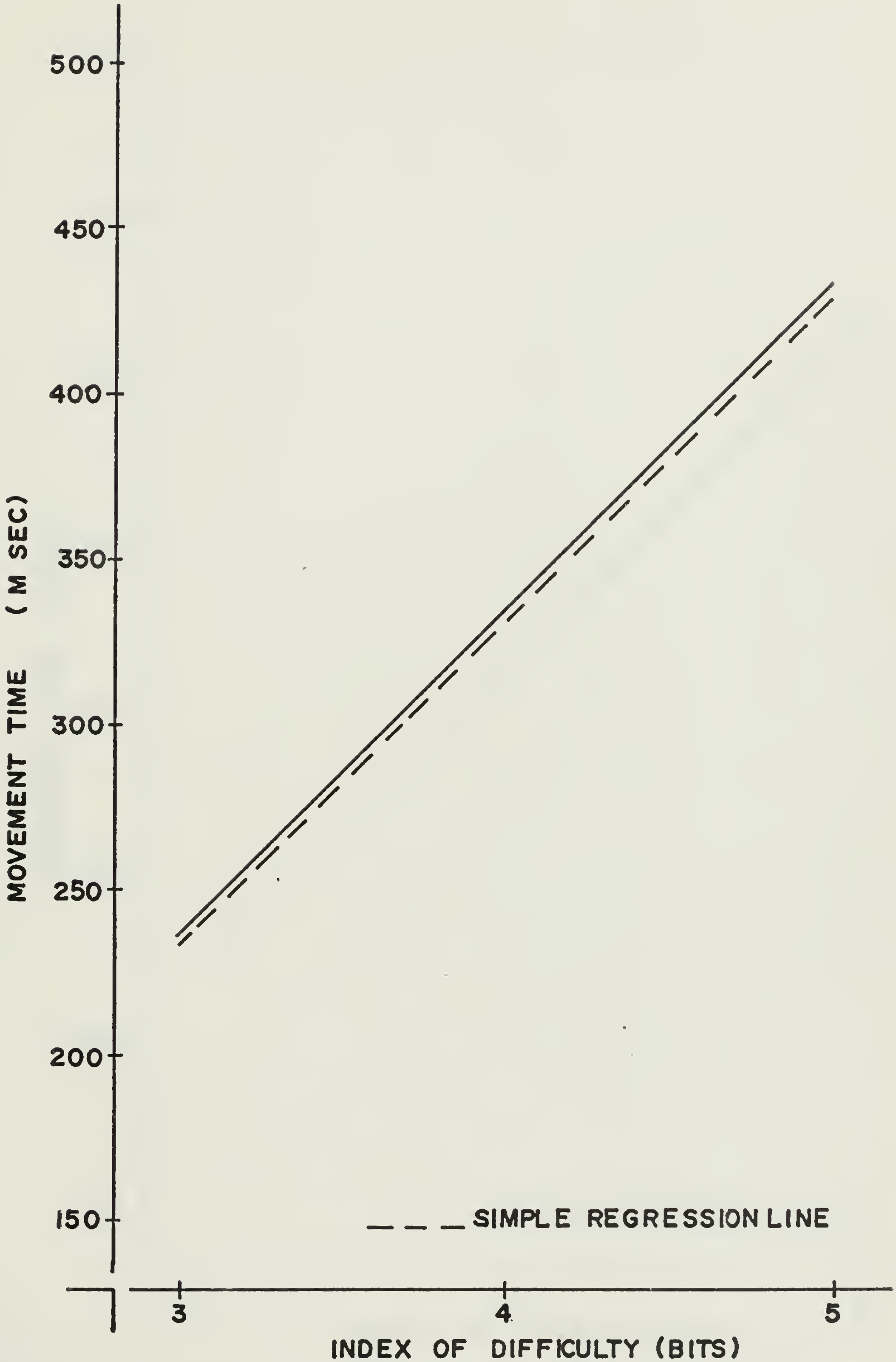

Figure 9e. Comparison of multiple regression line with simple regression line - direction 5.

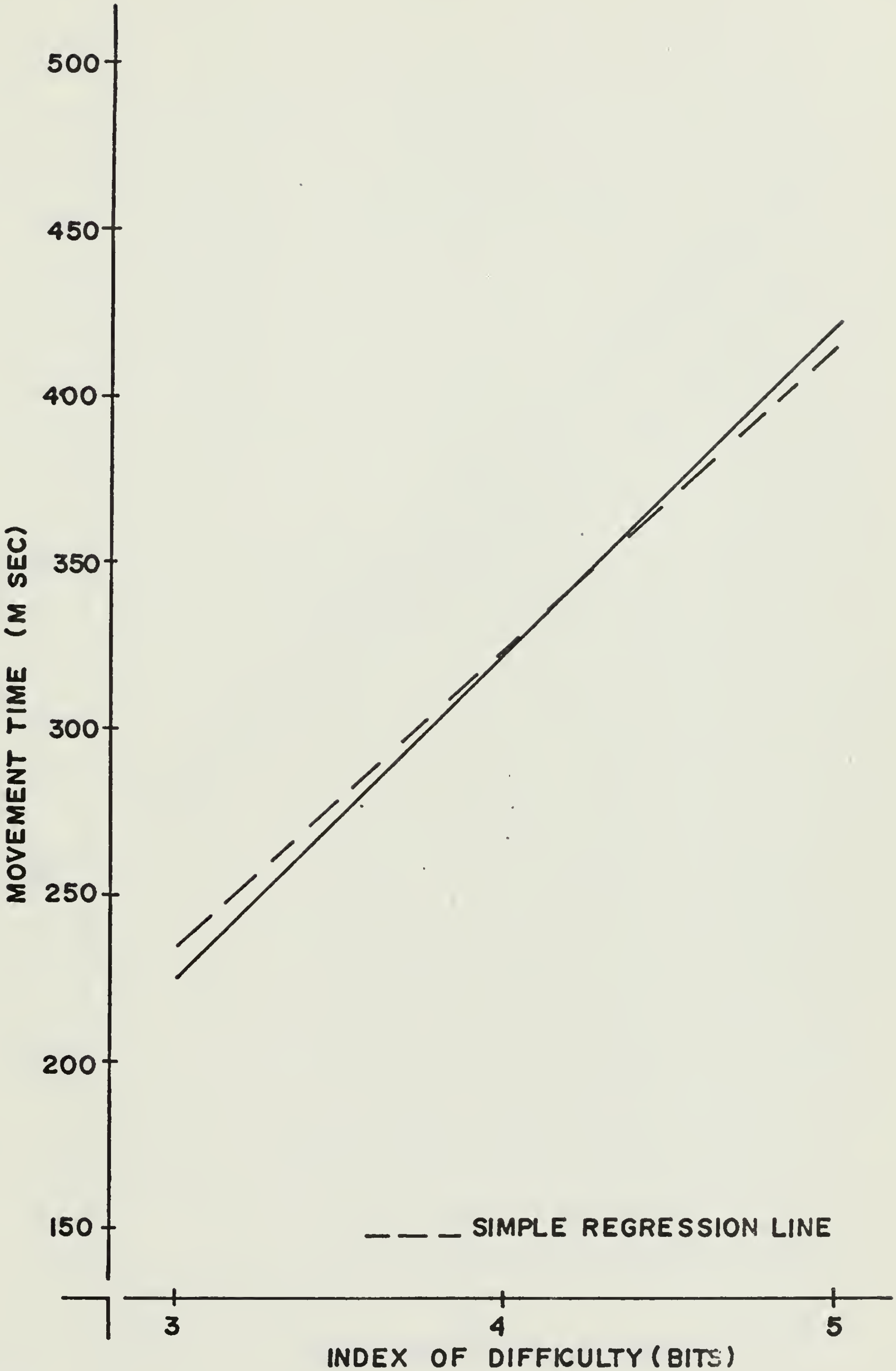

Figure 9f. Comparison of multiple regression line with simple regression line - direction 6.

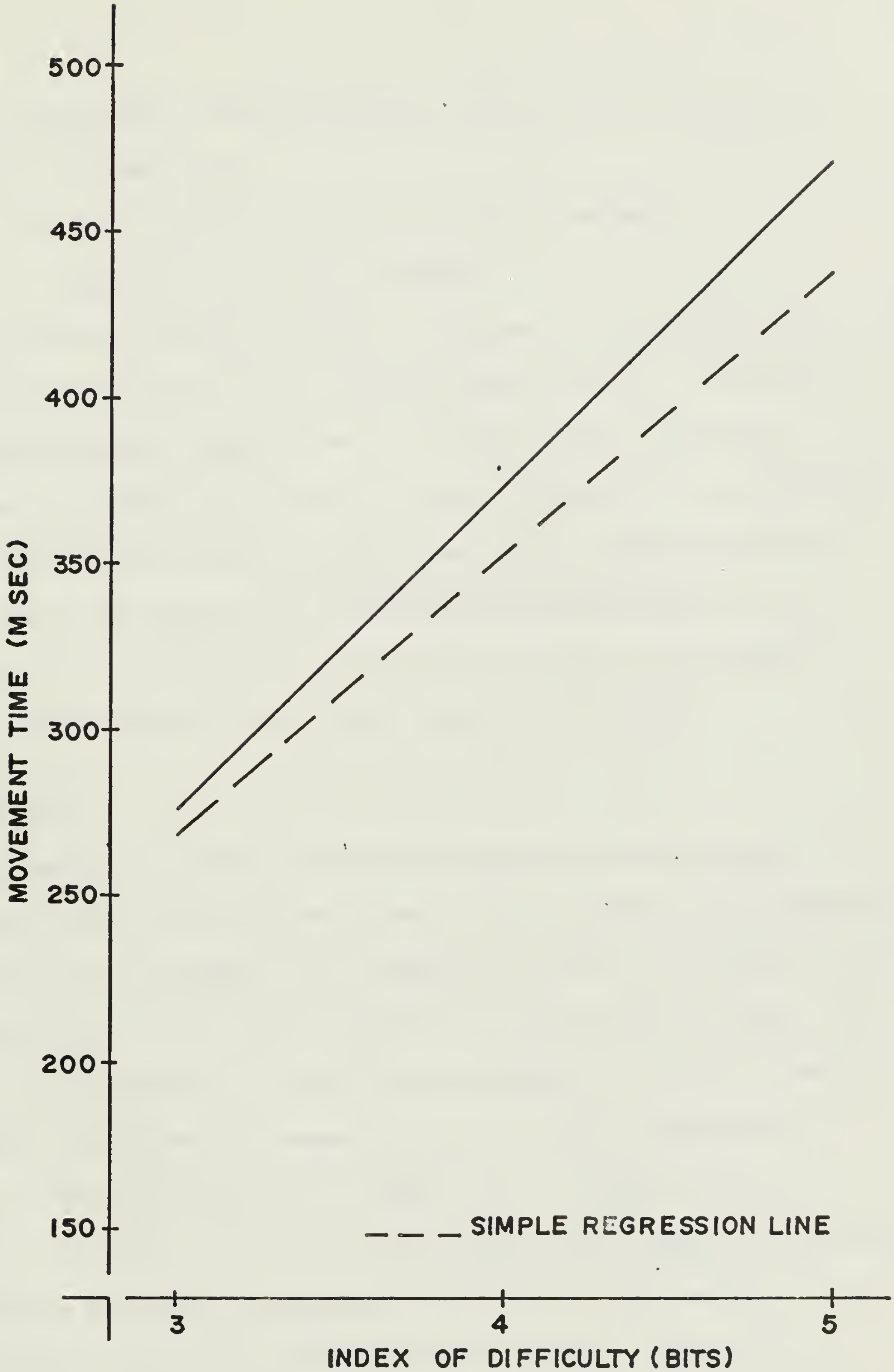

Figure 9g. Comparison of multiple regression line with simple regression line - direction 7.

The multiple regression equation found by use of the sine of the angle of movement was:

$$MT = -27 + 98\ ID - 20\ (\text{Sine } X)\ \text{msec, where } X =$$

angle of direction of movement.

For the variables in this equation, the R found by use of mean data was .96. The R found by use of all data points was .72. It can be concluded from this analysis that the multiple linear regression equations as developed here could be used to predict MT in any direction. This prediction would only be valid, however, for directional movements made in the same area of the horizontal plane as used in the experiment. This analysis was accomplished by use of the computer program BMD02R which is described in detail in Dixon (1965).

C. DISCUSSION

The analysis of the MT data showed that MT did differ between the seven directions of movement used in the experiment, and consequently that direction of movement was a significant source of variation for MT. Although there might be some question as to how strong the effect that direction of movement has on MT when considering the results presented in Table VII, it must be remembered that the results presented in Table VII were obtained by use of mean data. The ANOVA presented in Table II would be the more robust argument and it shows that direction of movement does have a significant effect on MT. The analysis of MT data further verified the strong linear relationship between MT and

ID as found by Fitts and Peterson (1964). The multiple range test and the regression analysis presented some evidence to support an argument that directions 1 and 7 should be treated separately and not as one direction as was done by Fitts and Peterson (1964). An explanation for this might be that in this experiment, the movement amplitude (A) was extended out to 16 inches. The longest A used by Fitts and Peterson was 12 inches.

Direction of movement was found to have no significant effect on RT. A result which is consistent with conclusions reached by Fitts and Peterson (1964) and by Brown and Slater-Hammel (1947). ID was found to have a significant effect on RT, but this effect was primarily evident when movements were made in directions 1 through 4. It is concluded that the overall effect that ID has on RT is very small, a conclusion also reached by Fitts and Peterson (1964). Since mean RT remains relatively constant for the 7 directions of movement and the 3 ID levels, an overall mean RT was computed and determined to be .23 seconds. This result is very close to that (.25) found by Brown (1947, 1948) in three separate studies in which a total of 51 subjects were used with a median age of 23 years. The mean RT found by Fitts and Peterson was approximately .29 seconds which was higher because of the uncertainty incorporated within the experiment.

The relative independence found to exist between the variables RT and MT certainly adds strength to the theory of independence

between perceptual processes and motor response processes. The general formula developed by use of stepwise multiple linear regression analysis for the prediction of MT is perhaps the most significant contribution made by this research. It allows the prediction of MT of discrete motor movements made in the area of the horizontal plane, such as would be used by an individual when working at a table, desk, bench or console. This area would seem to include most of the area where discrete movements are made by personnel who function as part of a man-machine system. The equation which makes use of the cosine function would be preferred because of the higher multiple correlation coefficients.

VI. CONCLUSIONS

The conclusions drawn from the results obtained from this experiment are as follows:

1. Direction of movement does have a significant effect on the movement times of individuals completing discrete motor tasks in response to a visual stimulus.

2. Direction of movement does not have a significant effect on the reaction times of individuals under the same conditions.

3. The effect of direction of movement on movement time can be characterized by an equation of the form, MT = a + b (ID) msec, when the direction of movement is one of the 7 directions used in the experiment. This relationship can be characterized in general for any direction of movement by an equation of the form,

   MT = a + b (ID) + c (Cosine X) msec, where X is the angle of the direction of movement.

4. The movement time of a discrete motor response is very highly correlated with the amount of information the movement is required to generate and the angular direction in which the movement is made.

5. Movement time and reaction time are measures of independent processes which are influenced quite independently by some of the same variables.

The conclusions are constrained by the conditions established by the experiment.

Recommendations for additional research on this subject are as follows:

1. The above experiment should be conducted with the use of left-handed subjects to determine if similar relationships exist between the variables.

2. A similar experiment should be conducted with the use of larger (or smaller) target widths (W) to determine if the same results are found at higher (or lower) ID levels.

3. An experiment should be designed and conducted which would include the same values for A and W that were used by Fitts and Peterson (1964), but which would also allow for directional movement. A more accurate comparison could then be made between the results obtained for directional movement and those obtained by Fitts and Peterson (1964).

4. Research should be conducted to determine which of the two equations for ID given by Fitts and Peterson (1964) is the best measure of the existing relationships. There is reason to believe that the equation for ID'(listed in Fitts' and Peterson's article as equation 10) provides a better theoretical foundation for the prediction of MT.

5. There seems to be no basis for further research on the relationship between ID and RT.

BIBLIOGRAPHY

Attneave, F., Applications of Information Theory to Psychology, Holt, Rinehart and Winston, Inc., New York, 1959.

Brown, J.S., and Slater-Hammel, A.T., "Discrete Movements in the Horizontal Plane as a Function of Their Length and Direction." Office of Naval Research, Special Devices Center, Contract N 5 ori - 57, Report 2, October 1947.

Brown, J.S., Slater-Hammel, A.T., and Bilodeau, E.A., "Characteristics of Discrete Movements in the Horizontal Plane When Executed With One and With Two Hands." Office of Naval Research, Special Devices Center, Contract N 5 ori - 57, Report 5, August 1948.

Brown, J.S., Wieben, E.W., and Norris, E.B., "Discrete Movements Toward and Away from the Body in the Horizontal Plane." Office of Naval Research, Special Devices Center, Contract N 5 ori - 57, Report 6, September 1948.

Dixon, W.J., BMD-Biomedical Computer Programs, University of California, Los Angeles, 1965.

Fitts, P.M. and Peterson, J.R., "Information Capacity of Discrete Motor Responses." Journal of Experimental Psychology, V. 67, p. 103-112, 1964.

Fitts, P.M., "The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement." Journal of Experimental Psychology, V. 47, p. 381-391, 1954.

McCormick, E.J., Human Factors Engineering, p. 219, McGraw-Hill, Inc., New York, 1964.

Miller, I. and Freund, J.E., Probability and Statistics for Engineers, p. 402, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1965.

Poock, G.K., Breen, W.W., and DeHaemer, J.J., "Comparison of the Effect of Auditory Versus Visual Stimulation on Information Capacity of Discrete Motor Responses." Journal of Experimental Psychology, V. 82, p. 395-397, 1969.

Raisbeck, G., Information Theory - An Introduction for Scientists and Engineers, Massachusetts Institute of Technology Press, Cambridge, Massachusetts, 1964.

Steel, R.G.D. and Torrie, J.H., Principles and Procedures of Statistics, p. 319, McGraw-Hill Book Company, Inc., New York, 1960.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Associate Professor G. K. Poock, Code 55PK Department of Operations Analysis Naval Postgraduate School Monterey, California 93940	1
4.	Major Edison Earl Scholes, USA P. O. Box 235 McCaysville, Georgia 30555	1
5.	Department of Operations Analysis, Code 55 Naval Postgraduate School Monterey, California 93940	1

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Information Capacity of Discrete Motor Responses Compared for Different Directions and Amplitudes of Movement

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Master's Thesis (September 1970)

5. AUTHOR(S) (First name, middle initial, last name)

Edison Earl Scholes

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1970	67	12

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

This report describes the research and analysis conducted to determine if direction of movement has an effect on the movement and reaction times of personnel when completing discrete motor tasks in response to a visual stimulus. Information theory was an inherent part of the research and was used to specify more precisely an individual's capacity in this area. Twenty subjects participated in the experiment and a total of 2100 data points were recorded for each of the variables, movement time (MT) and reaction time (RT). The results of the research and analysis showed that direction of movement did have a significant effect on movement time but no significant effect on reaction time. Linear models were developed which characterize the effect that direction of movement has on movement time. The linear models developed were of the forms,

MT = a + b (Index of Difficulty) and

MT = a + b (Index of Difficulty + c (Cosine X),

where X = angle of the direction of movement.

Multiple correlation analysis showed that a high, positive degree of correlation (R = .98) exists between movement time and the two variables - index of difficulty and direction of movement - used in the above models.

DD FORM 1473 1 NOV 65 (PAGE 1)

S/N 0101-807-6811

Security Classification

A-31408

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Discrete Motor Responses						
Information Theory						
Information Capacity						
Index of Difficulty						
Movement Time						
Reaction Time						

Thesis
S3413
c.1

119[illegible]95

Scholes

Information capacity of discrete motor responses compared for different directions and amplitudes of movement.